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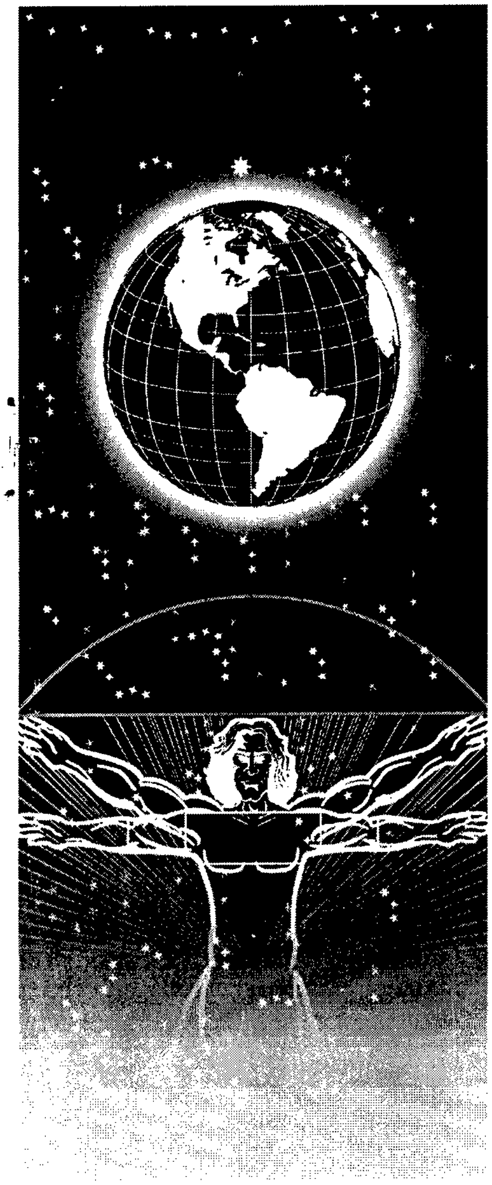

UNITED STATES AIR FORCE RESEARCH LABORATORY

ENABLING TECHNOLOGY: ANALYSIS OF CATEGORIES WITH POTENTIAL TO SUPPORT THE USE OF MODELING AND SIMULATION IN THE UNITED STATES AIR FORCE

Final Report of the Air Force Materiel Command
Air Force Research Laboratory Ad Hoc Working Group
on Modeling and Simulation Enabling Technologies

Dee H. Andrews
Jarvis Brown
Jack Byrnes
James Chang
Rob Hartman
Jeffrey Irwin
Michael Lightner
William McQuay
Allen Murashige
Alex Sisti
David Wintermute

May 1998

AIR FORCE RESEARCH LABORATORY
WARFIGHTER TRAINING RESEARCH DIVISION
6001 South Power Road, Building 561
Mesa AZ 85206-0904

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The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This paper has been reviewed and is approved for publication.

DEE H. ANDREWS
Technical Director

LYNN A. CARROLL, Colonel, USAF
Chief, Warfighter Training Research Division

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Dee H Andrews; Jarvis Brown; Jack Byrnes; James Chang;
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William McQuay; Allen Murashige; Alex Sisti; David Wintermute

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13. ABSTRACT *(Maximum 200 words)*
This report presents results of a research effort conducted at the request of AF/XOM to AFMC/ST to conduct a comprehensive review of long-lead, modeling and simulation-related technologies (both within and outside the USAF) to identify those areas that would be of high interest or significance to the USAF for constructive, virtual, live, or hybrid simulations, both local and distributed. The Ad Hoc Working Group on Modeling and Simulation (M&S) Enabling Technology (ET) adapted/developed a taxonomy consisting of five main categories: Interconnection Technology, Information Technology; Representation Technology; Interface Technology, and Pervasive Technology. The working group conducted a survey with representatives of the US Air Force, academia, industry, and Federally Funded Research and Development Centers to collect a sample of existing and planned ETs. The result of the survey was a set of subjective ratings of 93 ETs and 38 current M&S projects which make use of enabling technologies. Based mostly upon the Working Group's experience with M&S and upon the team's ratings of the ETs and M&S projects gathered during the survey, recommendations are made concerning the M&S ET projects and contain detailed rationale statements. The Ad Hoc team views the current effort as only the first phase to identify enabling technologies that have potential to improve the Air Force's M&S capability and strongly recommends that collection of ETs continues. For Phase II, they recommend that a group of M&S experts external to the Air Force continue this analysis with users of M&S ETs and the operational community. The ET users and operational community can identify operational "requirements pull" for M&S ETs that when combined with the "technology push" efforts identified in this report, can be used to build an Air Force ET investment strategy.

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FOREWORD

In defining the United States Air Force's (USAF) New Vector for Modeling and Simulation, the USAF Chief of Staff, General Ronald R. Fogleman, and Secretary of the Air Force, Sheila E. Widnall, stated, "We need to expand our involvement and investment in advanced simulation technologies to improve our readiness and lower our costs today, and prepare us to dominate the battles of tomorrow."

The rapid growth and expanding role of simulation in the Air Force and throughout the Department of Defense (DoD) attest to the tremendous power and potential that this technology provides to nearly every aspect of the defense enterprise. The Air Force, together with the rest of the DoD, is making a substantial investment in the development and use of simulation to support improved decision making, training, systems development, and testing. Many of the new Joint initiatives rely heavily on the ability of the Services to accurately represent, or simulate, their capabilities within a Joint synthetic battlespace in order to facilitate the planning and integration of these Joint forces in contingencies.

Within the Air Force, much of our modeling and simulation (M&S) emphasis has been on the end-use product, involving the application of existing simulation technologies to meet training or analysis needs. However, as our investment base grows, and as we engage in major, long-term, simulation projects such as the National Air and Space Model and the Joint Modeling and Simulation System (JMASS), it becomes imperative that we identify newly emerging or developing simulation technologies that may improve or alter our approach to future simulation capabilities. Further, if there are significant enabling technologies in development which appear to have unique applicability and high payoff for the Air Force, we should track these developments and focus our USAF investment strategy to ensure these technologies best meet USAF needs.

This survey was undertaken to obtain an initial, broad picture of the simulation science and technology landscape, with the goal of identifying the high points from an Air Force perspective. Because this is an initial attempt, and because the landscape is ever changing, we anticipate that refinements and periodic revisits will be necessary. To be comprehensive, breadth has been emphasized more than depth. The survey covered not only Air Force-sponsored activities, but activities of the other military services and DoD agencies, other agencies within the government, the Federally Funded Research and Development Centers, defense and nondefense industries, academia, and professional organizations.

It is our hope that the results of this survey will provide an indication of key technology push areas in simulation science and technology of which the Air Force should be aware. The balancing requirements pull aspect for simulation technology should come from the modeling and simulation Technical Planning Integrated Product Team process, as well as from the specific requirements of the major commands and M&S agencies. These technology push and requirements pull sources should help the Air Force construct a sound investment strategy for simulation technology that provides both quality and relevance for tomorrow's simulation needs.

HELMUT HELLWIG, Ph.D	CHARLES R. HENDERSON, Major General, USAF
Dep Assistant Secy of the Air Force	Director, Command and Control
(Science, Technology & Engineering)	DCS, Air and Space Operations

RICHARD R. PAUL, Major General, USAF
Commander, Air Force Research Laboratory
Air Force Materiel Command

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We wish to gratefully acknowledge the following individuals for the valuable assistance rendered to the Working Group in conceptualizing this analysis and in providing valuable feedback to improve the report:

- Dr Brendan Godfrey, the former Director of Armstrong Laboratory, and now the Director of Plans and Programs for the Air Force Research Laboratory, was instrumental in helping the team structure the analysis so that the result would meet the requirements of the Air Force. His detailed critique of the drafts of this report was very important.

- Mr Gary Yerace of the Defense Modeling and Simulation Office provided a number of good recommendations about individuals and organizations in the modeling and simulation community who might be interested in providing the Working Group information via our survey.

- Major General (Retired) Cecil Powell was key in persuading senior Air Force leaders that an analysis such as this would be valuable. In addition, he provided the team with valuable contacts for our survey.

- Mr Buzz Gillogly provided a number of contacts from industry for our survey.

ENABLING TECHNOLOGY: ANALYSIS OF CATEGORIES WITH POTENTIAL TO SUPPORT THE USE OF MODELING AND SIMULATION IN THE UNITED STATES AIR FORCE

EXECUTIVE SUMMARY

This report provides the results of a study performed by the Air Force Materiel Command (AFMC), Air Force Research Laboratory's (AFRL), Ad Hoc Working Group on Modeling and Simulation (M&S) Enabling Technology (ET). The goal of the effort was to identify enabling technology categories that could have substantial impact on the United States Air Force's (USAF) M&S applications in the future.

The Working Group adapted/developed a taxonomy of M&S enabling technologies which consists of five main categories: Interconnection Technology, Information Technology, Representation Technology, and Interface Technology. The fifth category, Pervasive Technology, which was added by the team, contains ETs that support the other four taxonomy categories. Each of the five main categories has a number of subcategories.

To aid the Working Group in its analysis, the Working Group team conducted a survey to collect a sample of existing and planned ETs. The enabling technologies identified from the survey are from the Air Force, academia, industry, and from Federally Funded Research and Development Centers. The result of the survey was a set of subjective ratings of 93 ETs and 38 current M&S projects which make use of enabling technologies. The team used the ETs and M&S projects identified to help evaluate the efficacy of the M&S taxonomy. We also used the ETs and M&S projects from the survey in developing a 6-factor rating process that can be used as a tool in helping to determine the value to the AF of ETs other than those examined in this analysis.

Based mostly upon the Working Group's experience with M&S, and in smaller measure, upon the team's ratings of the ETs and M&S projects gathered during the survey, we present our recommendations concerning the M&S ET subcategories that should be highlighted as M&S technology thrust areas having the potential to produce significant benefits for AF M&S applications. Of the 26 enabling technology subcategories defined by the team, the following 10 are recommended:

- Human Modeling
- Resolution and Validation Management Tools
- Design, Manufacturing, and Support Technology
- Model Management Tools
- Virtual Reality Technology
- Simulation Design/Experimental Frame Methodology
- Simulation Paradigms
- Hierarchical Simulation
- Knowledge Compendium Tools
- Model Abstraction.

We believe that any or all of the ten ET subcategories named above have the potential to produce significant dividends for the Air Force. The recommendations section contains detailed rationale statements for each of the ten ET subcategories that we highlight in this report. The report contains four appendices:

- Appendix A is the AF/XOM tasking letter which prompted this effort.

- Appendix B lists the organizations and individuals who are major players in the M&S ET community.

- Appendix C is a spreadsheet of subjective ratings for each of the ETs and Projects identified during the survey process. The ratings are based on six factors:

  - Importance of the ET and Project to the Air Force,

  - Maturity of the ET and Project,

  - Potential of the ET and Project for further development given increased investment,

  - ET and Project's position on a continuum with pure science as one anchor and immediate AF application as the other anchor,

  - Current level of development activity for each ET and Project, and

  - Uniqueness of the ET and Project to the military and especially the AF.

- Appendix D describes all ETs and M&S Projects that the Working Group collected from the survey.

The Ad Hoc team strongly recommends that collection of ETs continues. While we have assembled a large number (93) of ETs for this report, we realize that there are many more ETs in the M&S community (both inside and outside the AF) than we have been able to identify here. We recommend that this report be broadly distributed within the M&S community so that organizations and individuals who are currently not represented in the report may decide to participate as an ET and Project archive is developed by the AF.

We view our current effort as only the first phase of this initiative to identify enabling technologies that have potential to improve the Air Force's M&S capability. For Phase II, we recommend that a group of M&S experts external to the Air Force continue this analysis. In addition, we believe it would be very helpful to have a broad sample of users of M&S ETs, and the operational community, participate in a second study phase. The ET users and operational community can identify operational "requirements pull" for M&S ETs that, when combined with the "technology push" efforts we have identified in this report, can be used to build an Air Force ET investment strategy.

1.0 INTRODUCTION

In a letter to AFMC/ST (Appendix A), Maj Gen Thomas Case (AF-XOM) requested that AFMC/ST "conduct a comprehensive review of long-lead, M&S-related technologies (both within and outside the USAF) in order to identify those areas that would be of high interest or significance to the USAF for constructive, virtual, live, or hybrid simulations, both local and distributed. Particular R&D topic areas or Projects where USAF investment would be warranted should be highlighted." AFMC/ST (now Air Force Research Laboratory), Maj Gen Richard Paul, tasked Dr Brendan Godfrey (former Director of the Armstrong Laboratory) to organize an Ad Hoc Laboratory team to examine AF/XOM's request and conduct an analysis that would highlight promising enabling technologies that could have a substantial impact on the Air Force's modeling and simulation activities in the years to come. The resulting Ad Hoc team consisted of representatives from the Air Force Research Laboratory. Each individual on the team was considered by their organizations to have a good background in M&S. The Ad Hoc team also included Mr Allen Murashige from AF/XOM (now AF/XOC), who provided valuable information and insights from the XOM perspective. Dr Dee Andrews (AFRL/HEA), the Air Force Laboratory's Focal Point for Modeling and Simulation, chaired the team.

The working group met a number of times to determine how best to meet XOM's request and to analyze the enabling technologies identified in this effort. The working group first examined existing documents that address modeling and simulation within the Air Force and the Department of Defense. These included a 1993 survey of Air Force Laboratory models and simulations, called the Four Super Laboratories Modeling and Simulation for Science and Technology, or FourMOSST, and the two most recent Technical Area Review Assessments of modeling and simulation, sponsored by the Director, Defense Research and Engineering (DDR&E).

Members of the team had considerable experience in developing and using M&S enabling technologies. Although we could have performed this analysis relying only on our experience, we decided the analysis would be more robust if we also performed a survey to get a healthy sampling of existing and future M&S ETs. Our rationale for performing the survey was that the M&S field is so broad, it would be beneficial to collect a representative sample of extant ETs as a means to test the ET rating scale that we developed. We also felt that a representative sample of ETs would help us make better subjective decisions about which categories of enabling technologies seemed to have the most potential for future Air Force M&S work. We surveyed AF labs, the other Services, defense and nondefense industry, Federally Funded Research and Development Centers (FFRDCs), and academia.

We constructed the survey based upon the following questions:

- Technology Area (What enabling technology area does this response address?)

- Brief Description of the Technology Area (What is it? What aspect of M&S does it address? In what way is it different from the way we do simulation today? What is its significance to the field of M&S, and/or analysts or developers in the simulation community?)

- Degree of Maturity (Is the technology mature enough for application in Air Force programs? If not, please provide an estimate of when it might be.)

- Potential Air Force Application Area(s)/Benefit to the Air Force (As opposed to the benefit to the simulation community described above, how might insertion of this technology benefit the Air Force, and in what application area(s)?)

- Who are the major players/leaders doing research in this technology area? (Include yourself and/or others you are aware of. Please provide name, organization, phone, and e-mail address, if known.)

- Additional comments and your name, address, phone number, and e-mail address.

We sent this survey to over 200 M&S professionals in the sectors cited above in April 1996. Survey responses began to be collected in May of 1996. The team spent the summer of 1996 attempting to get more responses from organizations that did not respond to the first request. In addition, team members spoke with a number of survey respondents to clarify responses.

Appendix B lists all individuals and organizations who were identified in the survey responses as being major players in a particular ET or Project. Appendix D contains the results of the survey.

The final tally of usable survey responses was 131. Of the 131 responses, we judged that 93 responses described enabling technologies that were "pure." That is, the enabling technologies described in the responses could be used to support a wide variety of M&S efforts within the Air Force.

We judged that 38 responses were not "pure" ETs, but rather they were really descriptions of on-going projects, with very specific goals, that made use of M&S enabling technologies. These 38 responses did not represent "pure" enabling technologies because their products would not necessarily support a wide variety of other M&S efforts. We decided that they should still be included in our report for the following reasons:

- Although the end-products of these 38 projects are more focused than those described in the 93 "pure" ET responses, some of the projects' products can act as enabling technologies for other, larger M&S projects. In those cases, one can say that the project end-products are, in fact, enabling technologies.

- We believe the 38 project write-ups present valuable examples of how enabling technologies are being used in the M&S community and, therefore, their description should be maintained in the growing AF ET archive.

- Our current effort is ultimately a subjective process of deriving and recommending to higher authorities those ETs which we feel have good potential for AF use. The 38 projects have proven helpful to us as we have addressed which ET taxonomy subcategories to highlight in this report.

Clearly, the 93 ETs we collected represent only a portion of the ETs that are in the M&S community, both inside and outside the AF. For this reason, we believe it is important that this report be given wide dissemination in the M&S community so that organizations that are not represented in this report might participate in future AF efforts to build a viable ET archive.

2.0 ORGANIZING TAXONOMY

It became clear to the Working Group that there must be some scheme for organizing enabling technologies for M&S. The M&S field's breadth makes it necessary to categorize the many examples of ETs into manageable subcategories. We examined two existing taxonomies for organizing M&S enabling technologies. The first came from an Ad Hoc Working Group on M&S organized by the Joint Directors of Laboratories in 1993; the second, from the most recent DDR&E Technology Area Review Assessment for Information Systems. (Modeling and Simulation was a subarea under Information Systems.)

We felt that the second taxonomy better fit the data we had collected and so we adapted it. The major categories are Interconnection Technology, Information Technology, Representation Technology, and Interface Technology. The subcategory titles under each category were developed by the Working Group. We added an additional category to the DDR&E taxonomy called Pervasive Technologies. This last category contains enabling technology efforts that we feel cut across all of the other M&S technology areas. The five main taxonomy categories, and their subcategories, are as follows:

2.1 Category: Interconnection Technology

2.1.1 Subcategory: M&S Architecture
2.1.2 Subcategory: Distributed Communication Technology

2.2 Category: Information Technology

2.2.1 Subcategory: Simulation Support Tools

2.2.1.1 Model Management Tools
2.2.1.2 Resolution and Validation Management Tools
2.2.1.3 Simulation Design and Experimental Frame Methodology
2.2.1.4 Data Acquisition and Insertion

2.2.2 Subcategory: Hierarchical Simulation

2.3 Category: Representation Technology

2.3.1 Subcategory: Human Modeling
2.3.2 Subcategory: Environmental Modeling
2.3.3 Subcategory: Scientific & Engineering Modeling Methods
2.3.4 Subcategory: System Dynamics
2.3.5 Subcategory: Model Abstraction

2.4 Category: Interface Technology

2.4.1 Subcategory: Design, Manufacturing, & Support Technology
2.4.2 Subcategory: Exercise Management
2.4.3 Subcategory: Man-In-The-Loop
2.4.4 Subcategory: Virtual Reality Technology
2.4.5 Subcategory: Simulation Paradigms

2.5 Category: Pervasive Technology

2.5.1 Subcategory: Computer Processing Speed
2.5.2 Subcategory: Computer Storage & Retrieval
2.5.3 Subcategory: Desktop M&S
2.5.4 Subcategory: High Speed Data Transfer
2.5.5 Subcategory: Massive Parallel Processing
2.5.6 Subcategory: Object-Oriented Principles
2.5.7 Subcategory: Knowledge Compendium Tools
2.5.8 Subcategory: Expert Systems

In Sections 2.1 to 2.5 below, we present brief descriptions of each category and their subcategories. We also reference those descriptions of M&S ETs and M&S Projects in Appendix D that resulted from our survey. These subcategories are not mutually exclusive, so an ET or Project may be referenced in more than one subcategory. Of the 26 subcategories discussed below, the working group recommends that ten be highlighted. Those ten are identified and the rationales for our recommendations are discussed in the Recommendations section (Section 4.0) of this report.

2.1 CATEGORY: INTERCONNECTION TECHNOLOGY

M&S interconnection technologies enable creation or advancement of readily available and operationally valid environments for building and executing M&S applications. These technologies should allow maximum utility and flexibility in providing the capability to bring affordable, modular, reusable, and interoperable simulation components together in support of the Air Force customer. Technologies in this area include, but are not limited to, M&S architecture and infrastructure components, communications architectures and backplanes, application support services, protocols and standards, heterogeneous distributed networks, and dynamic multicast grouping techniques.

2.1.1 SUBCATEGORY: M&S ARCHITECTURE

M&S architecture technologies address the structure of components in a model, simulation or simulation system, their interrelationships, and the principles and guidelines governing their design and evolution over time. These technologies apply to one or more of the three broad classes of simulation (live, virtual, and constructive). The M&S architecture defines how to apply them across the functional domains of use (e.g., training, analysis, wargaming). This field of technology deals with the specification and implementation of architectural characteristics

which are common for components within, or across, models and simulations. M&S architecture addresses the concerns of structural representation of components at various levels of detail, reuse, portability, legacy interfaces, scalability, technological evolution, and distributed operation in either homogeneous or heterogeneous environments. A major goal when M&S architectures are used is the promotion of interoperability among models and simulations. Developing architectures for M&S requires the application of a broad range of already proven technologies in the areas of both computer science and M&S.

Within the DoD today, there is a major push towards developing standard M&S architectures which support a wide array of communities and a move away from the traditional stovepipe applications of M&S seen to date. Examples include the Joint Modeling and Simulation System (JMASS), which is focused on the tactical level of war; the Joint Simulation System (JSIMS), which is focused on the operational level of war; the Joint Warfare Simulation (JWARS), which is focused on joint campaign analysis; and High Level Architecture (HLA), which is focused on a communications architecture application for all domains.

Enabling Technologies and M&S Projects in Appendix D which are associated with this subcategory: 3, 12, 15, 17, 20, 22, 25, 33, 70, 84, 87, 90, 91, 115, 129

2.1.2 SUBCATEGORY: DISTRIBUTED COMMUNICATION TECHNOLOGY

Distributed communication technologies allow M&S capabilities to be expanded into a distributed environment. Such technologies allow communications between hardware platforms which are physically separated--sometimes by great distances. This technology area involves the application of many proven technologies such as client/server systems and wide-area communication bandwidths. Often the "glue" used to apply these technologies to the communication problem becomes a new technology in itself. One example is distributed, collaborative virtual prototyping which brings together the technologies of open systems architectures, distributed M&S, distributed design, desktop M&S, and many more. Another example of major DoD technology development in the area of distributed communication technologies is the High Level Architecture standard for networking.

Enabling Technologies and M&S Projects in Appendix D which are associated with this subcategory: 9, 11, 13, 71, 84, 87, 90, 91

2.2 CATEGORY: INFORMATION TECHNOLOGY

Information technology includes those efforts that enhance Modeling and Simulation interoperability, assess model and data quality, and provide for the development and adoption of simulation frameworks and tools to improve model and simulation development. Current research into simulation frameworks, also called architectures or infrastructures, is discussed in Section 2.1.1. The following sections introduce those enabling technologies and theoretical foundations that support future model and simulation design, construction, validation, interoperability, and analysis.

2.2.1 SUBCATEGORY: SIMULATION SUPPORT TOOLS

In the classic sense, simulation has long been viewed as comprising three basic phases: simulation setup, simulation execution, and post-run analysis and reporting. There has been considerable effort and money expended on the latter two phases; however, simulation design and setup as a technological discipline has not received much attention from the simulation research community. There have been some piecemeal and ad hoc improvements; e.g., graphical user interfaces and code-generating front-ends. However, there has not been a systematic effort to integrate the various support technologies that have been developed in simulation research circles. This section (2.2.1) discusses some of the more prevalent enabling support technologies as they relate to designing, configuring, and managing a simulation.

2.2.1.1 MODEL MANAGEMENT TOOLS

A key approach to developing quality model management tools is based on the concept of a model library. What is envisioned is not so much a physically manifested library, but rather a Virtual Model Repository (VMR), given the requirement to reuse as much legacy (i.e., validated) code as possible, and the fact that these models are independently owned and maintained, at sites distributed around the country. This VMR would consist of validated simulations, models, model components (at varying levels of resolution), data, and intermodel coupling relationships. These pieces would be selected, instantiated, and appropriately coupled to build the desired simulation through conformance to model and data format standards. This building process would be overseen by a Model Management System. A Model Management System in its most elemental form is to a Model Base (our VMR) what a database management system is to a database. It eases and, to some extent, automates the user's ultimate model selection.

Enabling Technologies and M&S Projects in Appendix D which are associated with this sub-subcategory: 10, 14, 15, 16, 43, 44, 46, 51, 68, 84, 85, 127

2.2.1.2 RESOLUTION AND VALIDATION MANAGEMENT TOOLS

These tools aid in the proposition, approval, and adoption of a definition of discrete levels of resolution or fidelity (the simulation community freely uses the term "fidelity" interchangeably with "resolution"). In order for the Model Management System to be of any utility, each component in the VMR must have a specific level of resolution associated with it, and it must have been validated as an accurate representation of the behavior of its real-world counterpart, at the prescribed level of fidelity.

There is a run-time aspect to resolution and validation management. The essence of the concept of Dynamic Resolution Management is that at certain stages of the simulation, either temporal or spatial, it makes sense to transition from modeling an entity or process at one level of fidelity to representing it at another. The need for such a transition, called a software zoom, could be either scripted or, more likely, could be dynamically deduced using a new concept called Significant Event Detection.

Enabling Technologies and M&S Projects in Appendix D which are associated with this sub-subcategory: 3, 5, 6, 7, 10, 17, 18, 21, 34, 35, 40, 42, 47, 49, 88, 93, 101

2.2.1.3 SIMULATION DESIGN AND EXPERIMENTAL FRAME METHODOLOGY

Simulation Design encompasses and overarches all subphases of the pre-simulation run stage, including the concepts of experiment frames, Model Management Systems, and other subphases of the pre-simulation run stage. As does its construction industry counterpart, simulation design speaks to the notion that one cannot jump into construction (in our case, a simulation) without a well thought-out blueprint.

Closely aligned with Model Management Systems is the concept of the Experiment Frame. An Experiment Frame enables the simulation designer or constructor to translate the objectives and issues to be addressed by a modeling effort into conditions under which experiments will be run with a model or real system. An Experiment Frame is a vital component of the Simulation set-up phase. This technology will allow the user to completely set up an experiment involving multiple executions of a single simulation with parameters changed for each run or execution of multiple simulations with varying parameters.

Enabling Technologies and M&S Projects in Appendix D which are associated with this sub-subcategory: 1, 14, 15, 16, 19, 20, 30, 60, 80, 81, 83, 84, 85, 86, 87, 90, 91, 102, 103, 120

2.2.1.4 DATA ACQUISITION AND INSERTION

This technology area refers to the users' desire to imbue their simulations with live, or real-time, input data. Some examples of this concept are: scanning circuitry schematic drawings as a way to set up appropriate simulations; scanning photographs, documents, and other forms of imagery; and driving existing flight simulations with real (or recorded) flight path or waypoint data.

Enabling Technologies and M&S Projects in Appendix D which are associated with this sub-subcategory: 14, 16, 37, 92, 97, 125

2.2.2 SUBCATEGORY: HIERARCHICAL SIMULATION

Hierarchical Simulation refers to the notion of a validated analytical hierarchy of models, consisting of several levels of modeling fidelity, ranging from most detailed (engineering level modeling) to most aggregated (theater- and campaign-level modeling). The basic idea of hierarchical simulation construction is to treat an engineering-level model, say a radar, as being a software zoom of its more coarsely modeled counterpart in a platform-level model; for example, an early warning radar on an aircraft. This platform-level model, in turn, can be viewed as a zoom of a rudimentarily modeled aircraft in a mission-level model; perhaps consisting of several aircraft in an air-to-air combat scenario. Finally, the highest level of the hierarchy is the theater- or campaign-level model, in which air-to-air combat is but one facet of the overall campaign.
If the objective of a particular simulation experiment is to assess the capability of an existing (or proposed) piece of equipment, or processing technique, a detailed model of that equipment or

technique is needed. Ideally (in order to assess its overall battle worthiness), it should be evaluated within the context of a theater-level simulation.

There are two alternatives for providing hierarchical simulation. The first, and probably the most prevalent approach taken by researchers, is called model integration. This involves actually replacing a coarsely modeled function or entity with a more detailed version--the software zoom mentioned earlier. Note that this still involves mapping all the input and output associated with each version so that their interconnections to the rest of the system can be resolved. Also, some degree of verification, validation, and accreditation needs to be made to ensure that the codes being swapped are both modeling the same thing, albeit at different degrees of fidelity.

The second alternative, model abstraction, is based on the concept that levels of detail (complexity, numbers of inputs and outputs, etc.) should be fairly consistent from component to component throughout the theater-level simulation. Model abstraction involves capturing the essence of the behavior of a model, without all the details of how that behavior is implemented in the detailed code.

The premise of Mixed Fidelity Simulation is that the appropriate level of resolution and fidelity should be determined by end-user requirements. The goal of efforts in this area is to provide a representation of entities and their behaviors sufficiently detailed to support the intended end-use yet avoids any unnecessary complexities. Avoiding such complexities reduces developmental and computational requirements associated with the simulation, enables the representational focus to remain end-use motivated, and reduces the false security that more is better.

Enabling Technologies and M&S Projects in Appendix D which are associated with this subcategory: 6, 7, 10, 17, 21, 23, 24, 25, 26, 27, 28, 29,30, 34, 40, 49, 53, 54, 59, 80, 82, 88, 101

2.3 CATEGORY: REPRESENTATION TECHNOLOGY

This area consists of work done to convert the raw materials provided by scientific studies and other data into fundamental building blocks suitable for constructing advanced simulations, often using general-purpose development tools. This technology brings in many variables including human modeling, environmental modeling, scientific and engineering modeling, system dynamics, and model abstraction.

2.3.1 SUBCATEGORY: HUMAN MODELING

This technology area consists of computer-generated forces that enable realistic simulations of large aggregates of forces with only a few, if any, people in the loop. It spans the spectrum of human biomechanical, physical, psychophysical and psychological parameters, responses, and interactions. It includes studies and models of individual and group behavior, and physiological models to enable more realistic simulations using a mix of real and semi-automated or computer-generated forces. Unconventional threats, such as those from radiation, lasers, and nuclear, biological, and chemical weapons present a number of very difficult and diverse operational issues for which we must improve our capabilities to predict the human response. These are often very difficult to accurately model due to the highly nonlinear nature of the phenomena, or

their human interaction characteristics. Major challenges include the rapid generation of near real-time interaction of these representations. The representation of human behavior must reflect human capabilities, cognitive processes, limitations, and conditions that influence behavior (e.g., morale, stress, fatigue). Cultural factors also may be significant. Providing variable human behavior for friendly, enemy, and nonhostile personnel remains a significant challenge.

Enabling Technologies and M&S Projects in Appendix D which are associated with this subcategory: 57, 58, 59, 60, 61, 62, 69, 97, 107, 108, 124

2.3.2 SUBCATEGORY: ENVIRONMENTAL MODELING

Environmental modeling represents natural and man-made environments that form the playing field on which lifelike simulations take place. In modern warfare, this playing field can range from beneath the ocean floor, up through the atmosphere, and into space. In all cases, the impact of the environment on military operations must be accurately taken into account within the simulation. Environmental modeling consists of adaptation of models of the environment (e.g., weather, oceanic circulation, radar, acoustic propagation, environmental ambient noise, smoke and obscurants, sensors, systems and platforms, etc.) for specific use in advanced simulations. This area also includes access and use of environmental databases in advanced simulations, and development of environmental displays that are not only realistic looking but accurate.

Multispectral environment modeling technologies are those technologies that address the needs for creating and maintaining common and consistent electromagnetic representations among all interactive participants in a Virtual Battlefield. The need for consistent environmental-effects representation is also important in the context of M&S standardization and simulation component reuse. Most detailed models with an environmental-effects function provide a single electromagnetic domain such as radio frequency (RF), millimeter wave (MMW), infrared (IR), near visual, or visual. The result is tight coupling of the simulated objects and the specific environmental effects modeled. The environmental effects need to be decoupled from the simulated user objects and combined into a single logical environment object in order to support reuse and interoperability. Environments must support all levels of fidelity and breadth of representation of electromagnetic and sonic environment effects. This affects background representations (earth and celestial bodies), atmospheric representations, and path propagation models (from tables to detailed physics).

Enabling Technologies and M&S Projects in Appendix D which are associated with this subcategory: 45, 63, 65, 66, 76

2.3.3 SUBCATEGORY: SCIENTIFIC & ENGINEERING MODELING METHODS

Scientific & Engineering (S&E) modeling, simulation, and analysis involves a broad variety of tools used to investigate, analyze, and develop experimental technology products for laboratory researchers. Similarly, manufacturers and designers use them to investigate, analyze, and develop weapon systems and production equipment for the operational Air Force. They support a range of Projects and tasks from tire design to detailed aircraft design; from basic physics of molecular actions in a gas to the shape of a wing spar fitting.

Models of weapon systems also support military-operations research analysis (wargames) with platforms that operate within-campaign mission and engagement simulations; e.g., planes, ships, and tanks. Game results and decisions are only as good as the fidelity of the platform's performance.

Networks are an extension of Computer-Assisted Design (CAD) which allow noncollocated multidiscipline projects. They also allow use of Man-in-Loop and Hardware-in-Loop systems, particularly where either or both are key to total system performance and are difficult to model realistically. The downside of CAD networks is that different applications have difficulty in sharing drawing and graphical data (files). Also, in real-time simulations, the line-carrying capacity and speed/latency representing multiple maneuvering platforms and weapons in conflict can be limiting.

Virtual Reality, also an extension of CAD, allows simulation developments which are dangerous to test in full scale (e.g., nuclear weapons). These are dependent on human cognition, reaction, or perception abilities (e.g., pilots, battle staff) and are not partial to conventional analysis (e.g., warhead fragmentation design).

Enabling Technologies and M&S Projects in Appendix D which are associated with this subcategory: 6, 23, 36, 37, 38, 52, 67, 72, 73, 74, 75, 78, 82, 84, 85, 86, 90, 92, 93, 94, 95, 96, 98, 102, 105, 106, 110, 111, 112, 113, 114, 117, 118, 120, 121, 122, 124, 128

2.3.4 SUBCATEGORY: SYSTEM DYNAMICS

This subcategory represents a time-based modeling of dynamic systems, where information, growth, products, etc., are represented by difference equations, and scenarios are driven by cause and effect feedback loops. Systems is used in the broadest sense: business, human, environmental, platform, and combinations. The discipline (body of knowledge and analysis techniques) is supported by an infrastructure of computer applications, case studies, university courses, text books, consultants, and a world-wide society and journal.

While the discipline has popular use in dynamic commercial systems, it has yet to become a common AF tool. It is very flexible, as evidenced by the fact that it can be used to assess the dynamic stability of an aircraft or to address policies of the AF Modernization Planning Process. AF and S&T examples may be:

- Acquisition Reform: Laboratory Policy
- Integrated Process Teams (IPT): Operational Policy
- AF Modernization Planning Process: Technology Planning Integrated Planning Teams
- Manufacturing Model: Lean Operations and Affordable Products
- Quality vs Quantity: A Robust Balance for the Threat
- In-house vs Contract Research: Balance for Technology Transition
- Senior Engineering Technology Area Review (SENTAR)
- Air Force Materiel Command Version of the Battle Lab: Impact
- Air Power Impact on the Land Battle: The AF Analysis
- Low Signature Impact on the Air Battle: How Much?

- Air Base Flexibility: Post-Cold War Policy
- On-board/Off-board Avionics, Sensors and Information Fusion: Fighters
- Pilot Training: The Balance between Simulation and Flight
- CAD Technology Network: Intra-Directorate and Lab-to-Industry

Enabling Technologies and M&S Projects in Appendix D which are associated with this subcategory: 55, 73, 77

2.3.5 SUBCATEGORY: MODEL ABSTRACTION

Model Abstraction is the intelligent capture of the essence of the behavior of a model without all the details, and therefore runtime complexities, of how that behavior is implemented in code. The intent of the modeler has always been to capture the essence of the behavior of the real-world entity or process, to whatever level of detail (complexity) he or she could afford, or was willing to wait for. Abstraction techniques range from lookup tables, where the entries are the outputs of many simulation runs of the detailed code, to performance curves and response surfaces. They also include mathematical metamodeling, which tries to reduce the behavior of a model to some mathematical equation (itself a model), involving the crucial input set. Traditional study in this area has dealt with reduced order polynomials comprised of these input factors. More recent research applies another pervasive enabling technology area--neural net, to represent reduced-order models. Another approach involves the use of rational functions.

One interesting advance in abstraction research has been the application and adaptation of the concept of qualitative reasoning, borrowed from the field of Artificial Intelligence. Qualitative Simulation, as this application is called, departs from the idea of exactness, the mindset of traditional (quantitative) simulationists. Some ancillary topics of research in qualitative simulation are: Fuzzy Modeling, Random Set Theory, Possibility Theory, Rough Set and Dempster-Shafer Theory, and Ordinal Optimization. The common factor is that all strive to represent intermediate degrees of truth (uncertainty) in such a way as to attain <u>optimal</u> answers, or ranges of answers, as opposed to an <u>optimum</u> answer of seemingly high precision.

The requirements for mixed fidelity composition, for representing models at varying degrees of resolution, and for reducing the complexity of monolithic legacy code are widely stated by all the services. There is much research under way, using a wide variety of approaches. However, it is a fairly immature discipline, with few actual prototype implementations in place.

Enabling Technologies and M&S Projects in Appendix D which are associated with this subcategory: 7, 10, 17, 21, 23, 24, 25, 26, 27, 28, 29, 30, 34, 40, 49, 53, 88, 101

2.4 CATEGORY: INTERFACE TECHNOLOGY

The purpose of Interface Technology (IT) is to communicate information between two or more independent models or simulation entities such that the combination(s) act as a single integrated unit with greater functionality. The IT may be embedded in one or more of the separate units or it may be a stand alone.

2.4.1 SUBCATEGORY: DESIGN, MANUFACTURING, & SUPPORT TECHNOLOGY

Integrated systems have the advantage of speed of total analysis, minimization of manual error, and the ability to adapt proven legacy models. The final product serves a higher level decision maker. There are some disadvantages of using integrated systems, such as the requirement for a higher level analyst or team to use such models. Integrated systems allow companies to collaborate on development via virtual collocation of multidiscipline design and project groups. Computer systems specialists are needed to maintain such models.

Architectural modularity provides reuse, reconfiguration, and upgrade flexibility for a new application or for proprietary alteration to an Industry Standard Model. An advantage of this modularity is that pre- and post-processors can be developed or adapted from proven Commercial Off-the-Shelf applications (databases, spreadsheet, etc.). This type of modularity adds value by making data more understandable.

Groupware is a new category of software depending on a network infrastructure. Groupware facilitates organizational learning.

Enabling Technologies and M&S Projects in Appendix D which are associated with this subcategory: 4, 41

2.4.2 SUBCATEGORY: EXERCISE MANAGEMENT

Exercise management technologies enable the effective managing of all the assets required to execute a simulation or federation of simulations. Examples of simulation assets that must be managed during execution include hardware, such as computer processors, communications bandwidth, secure operations gear, and actual hardware-in-the-loop, as well as the digital models and support infrastructure components which come together to make up and define the exercise. This is already a challenging area for simulation exercises. Additionally, with the rapid advance towards the use of heterogeneous, distributed high performance modeling, the difficulties and timing necessary in managing this complex set of assets is compounding rapidly.

Technology is required in the form of software and hardware tools to aid the human exercise manager/director in effectively managing the simulation environment. Areas where technology is needed include, but is not limited to, tools that provide dynamic load balancing, simulation environment monitors and controllers, fault detection and compensation, resource monitors, etc.

Enabling Technologies and M&S Projects from Appendix D which are associated with this subcategory: 46, 89, 103

2.4.3 SUBCATEGORY: MAN-IN-THE-LOOP

Virtual Simulations inject man-in-the-loop (MITL) in a central role. People portray themselves within these simulations by exercising motor control skills (e.g., flying an airplane), decision skills (e.g., committing fire control resources to action), or communication skills (e.g., as

members of a C4I team). These simulations are highly interactive, with the virtual reality being provided by computer-driven displays and interaction interfaces.

Enabling Technologies and M&S Projects from Appendix D which are associated with this subcategory: 1, 5, 103, 119, 128

2.4.4 SUBCATEGORY: VIRTUAL REALITY TECHNOLOGY

In addition to the conventional computer inputs mechanisms (e.g., keyboard, mouse), Virtual Reality (VR) inputs include all measurable human responses, both voluntary and involuntary. Head, eye, finger, and limb movements and position, and voice have been used or demonstrated. Also, psychomotor or task-following responses have proven helpful. Other involuntary inputs are strength, heart rate, temperature, blood pressure, brain waves, perspiration, vertigo, nausea, breath rate, salivation, eye movement, and tactile feedback.

Visual imagery, via computer graphics, is the primary sensory input to humans using VR. To a lesser degree, sensory input includes stimulation of the human sensory system via motion (including acceleration and speed), position, vibration, sound, smell and feel (including touch, heat, cold, wind, rain, pain), etc. Other humans are possible input actors, either pre-scripted or as part of a group experiment (e.g., the Battle Staff).

VR may be designed to give the human a God's eye view of an event. For example, molecular bonding or a nuclear explosion may take understanding before analysis. Other VR interfaces are between VR nodes; such as the Defense Advanced Research Project Agency's (DARPA) Distributed Simulation Internet (DSI), which simulated armored vehicles on a battlefield.

The output mechanisms for VR often are not very user friendly, and authenticity and immersion may be difficult to achieve. Current VR output mechanisms include head sets, gloves, boots, clothes, g-suits, limb controls, platforms, vision rooms, etc. Proper placement and emphasis of the VR sensory output (to a human) in a story line (scenario) is essential toward attaining a realistic human response. The brain's expectations (the mind's eye) due to previous or perceived experience may help with this output problem. However, previous experience frequently exacerbates the problem.

The goal is then to translate these human outputs to cognitive, behavioral, interaction, judgmental, and emotional abilities. This might be considered to be a post-processor task.

Enabling Technologies and M&S Projects from Appendix D which are associated with this subcategory: 39, 97, 103, 116, 129, 130

2.4.5 SUBCATEGORY: SIMULATION PARADIGMS

An important area of research in simulation science involves investigating new simulation paradigms. Whereas traditional approaches have been adequate for the body of problem-solving applications for which they have been used, the problems confronted by designers, analysts, and decision-makers of today imply the need for new ways to represent the behavior of real-world

entities, processes, and their interactions. New ways of presenting simulation results and data, and new ways of executing a simulation experiment are required. There are many reasons why new ways are required; however, they can be reduced to two basic areas: (a) New paradigms are needed to take full advantage of advances in other technology areas (e.g., increased capabilities of hardware now allow problems of enormous complexity to be run) while some requirements have arisen due to an increased acceptance of simulation as a tool, and (b) the user community's desire to extend its utility.

Traditional modeling paradigms (discrete-event system modeling, continuous system modeling, Monte Carlo simulations) evolved from the capabilities of the hardware, software, and mathematical techniques of their time. However useful they had been, these paradigms are now giving way to new modeling styles that are more intuitive and natural (Object-Oriented Simulation, Fuzzy Logic, Generative Analysis, Multi-Modeling/Multi-Faceted Modeling and paradigms based on the Petri Net and Neural Net), quicker (Parallel and Distributed Simulation and Concurrent Simulation), more accurate (Hierarchical Simulation or Mixed Fidelity Simulation), and more dynamic and interactive (Web-Based Simulation, System Dynamics modeling, Adaptive or Heuristic Simulation, and Man- or Hardware-in-the-Loop Simulation). Specific developments in these areas are dispersed throughout this report, and more detailed examples can be found in Appendix D.

Enabling Technologies and M&S Projects from Appendix D which are associated with this subcategory: 8, 9, 10, 12, 13, 17, 21, 26, 27, 28, 29, 30, 31, 32, 33, 35, 40, 47, 48, 52, 54, 56, 70, 79, 84, 86, 88, 91, 99, 101, 104, 108, 115, 116, 117, 123, 125

2.5 CATEGORY: PERVASIVE TECHNOLOGY

These technologies are external to the modeling and simulation realm, but support modeling and simulation by providing the capabilities upon which modeling and simulation depends. For the most part, these are the hardware and software technologies that make up the computer itself.

2.5.1 SUBCATEGORY: COMPUTER PROCESSING SPEED

The speed at which a computer performs logical or mathematical operations governs the time required to perform a simulation. Improvements in computer speed provide shorter simulation run times and quicker turn-around times.

The importance of this technology to the Air Force is high. While the technology's maturity is only rated as moderate, its high activity level promises that its full potential may well be met within a few years. Computer processing speed has been steadily increasing and is approaching what appears to be its physical limits. All simulation and computer programs would benefit from increases in computer processing speed. The military, other government funding agencies, industry, and academia have invested considerable resources over the years to make computers run faster. This investment continues at a high rate. In virtual systems, improvements in computer speed also allow the use of higher fidelity visual systems, thereby increasing the number of training events requiring visual acuity that can be performed in simulation.

Enabling Technologies and M&S Projects from Appendix D which are associated with this subcategory: 50, 71

2.5.2 SUBCATEGORY: COMPUTER STORAGE AND RETRIEVAL

The amount of data storage or memory in a computer contributes greatly to the level of detail and scope of simulation programs. The speed at which the data is stored and retrieved affects both the setup and run times for simulations. As models increase in their scope and their level of detail, their size and memory requirements also increase. Data storage is unlimited off the computer, but its storage and retrieval make it cumbersome for simulation use. An infinite virtual memory or Random Access Memory (RAM) is the most desirable during a simulation run because of its instant access. However, the size and infrequency of use for some subroutines suggest they not be called from the computer's memory. The delays in data retrieval interrupt the simulation flow and delay its completion.

The importance of this technology to the Air Force is high. While the technology's maturity is rated as moderate, its activity level is moderately high. However, the growth of programs requiring massive memory leaves us with only a moderate assurance that this technology will meet its full potential in a relatively few years.

Not only must computer memories be expanded to allow for larger data files, but the speed of the data retrieval must be accelerated to rival the instantaneous access of RAM. Fixes in these areas would allow for large-scale, high-fidelity models. Enabling Technologies and M&S Projects from Appendix D which are associated with this subcategory: 50

2.5.3 SUBCATEGORY: DESKTOP M&S

Desktop Modeling and Simulation refers to providing extensive modeling and simulation capabilities to the desktop computer of the analyst. It is a move away from the large mainframe computers to personal computers, which is facilitated by increased computing speeds and improved memory and retrieval mentioned above. It also refers to more user-friendly simulation programs and multiplexed computers. Desktop M&S should provide cost-effective and efficient environments for executing simulations in a PC environment in such a way that they interoperate with simulations executing on workstations, computational servers, and other processors. Desktop M&S technologies are needed to address the areas of development, configuration, execution, and post-execution processing of simulation results. The technologies needed to support M&S are many and cross many of the other technology areas, both M&S and Computer. Desktop modeling systems include the following characteristics:

- Open systems architecture supporting applications conforming to commercial and industry standards
- Visual paradigm: Visual programming, visual assembly, visualization of output results
- Object based to allow component reuse
- Extensible architecture for future software concepts
- Execution on distributed heterogeneous network of workstations and upscale PCs
- Tools to support development of model components

- Multiple language support--the user can specify the target source language (C, C++, Objective C, Ada83, Ada95, VHDL, etc.)
- Object-oriented database
- Tools and models support a Plug-and-Play concept
- Supports "distributed model development" by the domain experts as opposed to central model development by software experts
- Interface to a repository of models and their components
- Documentation designed to support software reuse
- Automated verification and test
- Ability to interface to IEEE Distributed Interactive Simulation (DIS) standard and the emerging High Level Architecture (HLA) paradigm

Enabling Technologies and M&S Projects from Appendix D which are associated with this subcategory: 85, 131

2.5.4 SUBCATEGORY: HIGH SPEED DATA TRANSFER

High Speed Data Transfers refer to the near instantaneous transmission of large amounts of data across thousands of miles so that multiple remote simulations can interact seamlessly. Current technology requires noticeable waits for data transmission of large files. As the Air Force moves toward larger scale synthetic battlefields that incorporate live, virtual, and constructive components, there will be a greater need for moving information around the synthetic battlefield networks.

Enabling Technologies and M&S Projects from Appendix D which are associated with this subcategory: 32, 49, 50, 127

2.5.5 SUBCATEGORY: MASSIVELY PARALLEL PROCESSING

Massively Parallel Processing is a move away from the serial processing that most programs employ. Today most programs are designed to work on one computer and perform operations one after another in a serial fashion. Parallel processing employs the use of multiple processors which simultaneously run different parts of the program, integrating the partial solutions into the final result. Multiple parallel computers significantly shorten the time required to complete a program. Considerable investment in this technology has been, and is currently being, provided by the military, other government funding agencies, industry and academia.

Enabling Technologies and M&S Projects from Appendix D which are associated with this subcategory: 31

2.5.6 SUBCATEGORY: OBJECT-ORIENTED PRINCIPLES

Object-oriented programming is a natural and intuitive way of representing and coupling software components. It is a well-founded software science paradigm that allows less-experienced users to program and run software applications. Extending the application of object-oriented techniques to the modeling (i.e., representation) and simulation of complex entities and

systems, such as aircraft, sensors, weapons, and C4I systems, would greatly facilitate their creation, insertion, and interoperability. This extension would ultimately allow an untrained user, such as a warrior, to be able to understand the simulation objects enough to program, run, and assess the results of a simulation. An object-oriented simulation enables the designer or user to more naturally represent the various types of relationships among these entities and systems, as well as their relationships with their human operators. The semantics of these relationships are particularly important, transcending what is currently supported in object-oriented programming languages.

Another area of research addresses the attempts of the simulation community to create object-oriented simulations without a clear engineering approach to building models. The emerging area of model engineering is as significant a method in simulation science as was software engineering in the computer science field. The Object-Oriented paradigm, as a computer science discipline, is quite mature, dating back over 25 years. However, the application of object-oriented principles to modeling and simulation of complex systems is still relatively new. Model Engineering holds much promise as a disciplined approach to simulation construction, and object-oriented database technology is as important and relevant a research area today as general database technology was in the 60s and 70s.

Enabling Technologies and M&S Projects from Appendix D which are associated with this subcategory: 8, 48, 51, 54, 56

2.5.7 SUBCATEGORY: KNOWLEDGE COMPENDIUM TOOLS

These tools are software programs designed to capture the information, insights, procedures, and processes used by experts or experienced professionals. The purpose of such a capture is to preserve their expert knowledge even after they have retired. Such knowledge could be used to improve others' performance and train newcomers to the field. The Knowledge Compendium tool is used by a knowledgeable group or individual traversing the analysis of a specific problem. During analytical travel, specific data/information is needed to anchor or decide uncertainties and assumptions; thus, solution rigor and traceability are added. As a result, both analysis time and risk can be reduced. The purpose is to have an information base tool similar in concept to a data base tool.

For past and present analysis and testing which has undergone/is undergoing expert evaluation, conclusions and recommendations would be available for aid in sorting, selecting, prioritizing, reanalyzing, and learning. It includes such subtools as hypertext, graphics, brainstorming, cause-and-effect routines, histograms, etc. Compared to an expert system, a Knowledge Compendium is, in a sense, a readily available raw data bin. A Knowledge Compendium differs from an expert system in that the information has been synthesized by an expert. Use of a Knowledge Compendium will not necessarily lead the user through a logical path to an answer or solution. Hence, it may be less structured, more flexible, and more dynamic than an expert system. It is usually less quantitative as well.

When using either a Knowledge Compendium or an expert system, some degree of preparation is required. It is entirely possible for an artificial intelligence tool to be included as part of a

Knowledge Compendium tool. Each Knowledge-Based Compendium (KBC) would focus on a particular function or organization; for example, Air War College, ceramics, Investment Strategy, etc. It would be dynamic: first, it would be continually updated; and second, if the focus was multidisciplined, (e.g., aircraft design), it may be handled by a group. Such groups could be collocated or networked together (virtual collocation).

Enabling Technologies and M&S Projects from Appendix D which are associated with this subcategory: 14, 43, 44, 68, 100

2.5.8 SUBCATEGORY: EXPERT SYSTEMS

Expert systems are the converse of knowledge compendium tools. They are the software programs that advise people about the best procedures and processes to use in specific situations. They may also advise individuals about the expected results derived from following other, less desirable, courses of action. They are the computerized mentors that provide insight to people based on the experiences of experts who have earlier met similar situations and have recorded their observations with knowledge compendium tools.

Enabling Technologies and M&S Projects from Appendix D which are associated with this subcategory: 25, 26, 27, 29, 109

3.0 AD HOC TEAM'S RATINGS OF THE M&S ENABLING TECHNOLOGIES AND M&S PROJECTS COLLECTED IN THE SURVEY

3.1 METHOD

Appendix C consists of a spreadsheet which contains the Ad Hoc team's ratings for the 131 survey responses that were returned to us. To rate each ET or M&S Project, we developed a 6-factor rating scale. The six factors are:

- Importance of the ET or M&S project to the Air Force
- Maturity of ET or the M&S project which uses an ET(s)
- Potential of the ET or the M&S project to reach maturity
- Where the ET or M&S project lies on a pure science to pure application continuum
- Current activity level on that ET or M&S project
- Uniqueness to the Military, especially the Air Force, of the ET or M&S project

The rating scales are only shorthand methods for reflecting the team's subjective judgments about various aspects of each ET or M&S Project. This rating scale approach allowed team members to quantify their subjective opinions via numerical ratings.

The specific descriptions of the rating scales' anchor points are as follows:

- "**Importance of the ET or M&S project to the Air Force**" is rated on a 1-5 scale. The rating scale anchor points are defined as follows:

1 = No importance to the Air Force; the Air Force would never have a use for this ET or Project
2 = Some importance to the Air Force; however, the Air Force can probably get by without this ET or Project
3 = Considerable importance to the Air Force; the Air Force needs this ET or Project
4 = Significant importance to the Air Force, the Air Force will be severely hampered without this ET or Project
5 = Critical to the Air Force; the mission of the Air Force will not be achievable without this ET or Project

- **"Maturity of the ET or M&S project"** is rated on a 1-5 scale. The rating scale anchor points are defined as follows:

1 = ET or Project is completely mature; no further development is required
2 = ET or Project is mature but could use more development for refinement purposes
3 = ET or Project is not mature; some additional work is required
4 = ET or Project is not mature; significant additional work is required
5 = ET or Project is only in the initial stages of development; maturity will not be achieved for some years to come.

- **"Potential of the ET or M&S project to reach its maturity"** is rated on a 1-5 scale. The rating scale anchor points are defined as follows:

1 = ET or Project has no potential for reaching full development regardless of additional investment of resources, **or** ET or Project has already reached its full potential.
2 = ET or Project has little potential for reaching full development, even with additional investment of resources.
3 = ET or Project has fair potential for reaching full development with additional investment of resources.
4 = ET or Project has considerable potential for reaching full development with additional investment of resources.
5 = ET or Project has tremendous potential for reaching full development with additional investment of resources.

- **"The location of the ET or M&S project on a Pure Science to Pure Application Continuum"** is rated on a 1-5 scale. Rating scale anchor points are defined as follows:

1 = ET or Project has been, or will be, developed for immediate application to an Air Force challenge; it has scientific elements but it was not developed for scientific purposes.
2 = ET or Project was, or will be, developed mostly for immediate application, although it also has some scientific purposes.
3 = ET or Project was, or will be, developed for both immediate application and scientific purposes; it has a clear dual purpose.

4 = ET or Project was, or will be, developed mostly for scientific purposes, although it also has some immediate application to Air Force challenges.
5 = ET or Project has been, or will be, developed for scientific purposes only; it may have an application to Air Force challenges in the future but not right now.

- **"Current Activity Level on the ET or M&S Project"** is rated on a 1-3 scale. The rating scale anchor points are defined as follows:

1 = ET or Project has a high current level of activity, including a high investment of resources either from the AF, other sources, or both.
2 = ET or Project has a medium level of activity.
3 = ET or Project has a low level of activity.

Our rationale for this last scale was that the higher the past or current level of activity (investment), the less need there was for future investment. Therefore, the more the current or past activity, the lower the score.

The rater's judgment is based on the rater's understanding of the current level of activity or investment that is being made. In some cases, the ET or Project write-up allowed the rater to answer this question. In other cases, the rater may have had personal knowledge about the activity level, which was gained outside the immediate survey. In some cases the rater may not have been able to determine what level of activity is currently underway, in which case, the rater answered "Don't Know." If a rater responded with a "Don't Know," he simply skipped giving a score for this rating scale for this particular ET or Project. It should be noted that we did not ask the survey respondents to give funding levels. Our experience has been that requests for such information seldom meet with success.

- **"Uniqueness to the Military, especially the Air Force, of the ET or M&S Project"** is rated on 1-3 scale. The rating scale anchor points are defined as follows:

1 = ET or Project is a technology that is of interest and use to any organization performing M&S work.
2 = ET or Project is a technology that might be used outside the military, but is generally used by the military.
3 = ET or Project is a technology which would only be of interest and use to the military.

In many cases, the rater had special knowledge of the ET or Project or the field in which the ET or Project would have the greatest impact, because the rater had some involvement with the ET or Project outside of this survey. If so, the rater's ratings were counted twice. We felt such a weighting was justified, because detailed knowledge of a particular field or ET or Project meant the rater's opinion was grounded on more than merely the ET or Project write-ups.

Finally, a topic of special interest to the AF Chief of Staff is making sure the AF is properly and accurately represented at the campaign level of M&S. If any of the raters felt the ET or Project would have a potential impact on campaign-level modeling, a "Y" for Yes was placed in the appropriate column in the spreadsheet at Appendix C.

3.2 RESULTS OF THE RATING PROCESS

Rankings for Taxonomy Categories and Subcategories. The results of the rating process are shown in Appendix C which is arranged by the M&S Taxonomy categories and subcategories described in an earlier section. Many ETs and M&S Projects fall into more than one Taxonomy subcategory, and therefore the reader will see the ratings of certain ETs and M&S Projects appear more than once in the Appendix C spreadsheets. The average of all of the mean rating scores for each ET or M&S Project is shown at the end of each taxonomy subcategory section in Appendix C. In addition, the standard deviation is shown.

Rankings of Taxonomy Categories when the 38 M&S Projects are combined with the 93 Enabling Technologies. When the M&S 38 projects are combined with the 93 ETs, and the average for each taxonomy and subcategory is calculated, the following ranking results:

Rank	Taxonomy Category or Subcategory		Number of ETs/Projects in Category or Subcategory	Average Rating Score Across Category or Subcategory
1	2.3.1	Human Modeling	4	17.4
2	2.2.1.4	Data Acquisition and Insertion	6	17.0
2	2.5.2	Computer Storage and Retrieval	1	17.0
4	2.2.1.2	Resolution and Validation Management Tools	17	16.9
5	2.1.1	Modeling and Simulation Architecture	15	16.5
5	2.4.1	Design, Manufacturing, and Support Technology	2	16.5
7	2.4.4	Virtual Reality Technology	5	16.3
8	2.4.5	Simulation Paradigms	37	16.2
9	2.3.5	Model Abstraction	16	16.1
9	2.2.2	Hierarchical Simulation	22	16.1
11	2.2.1.3	Simulation Design/Experimental Frame Methodology	21	16.0
11	2.4.2	Exercise Management	4	16.0
11	2.4.3	Man-in-the-Loop	5	16.0
13	2.5.6	Object-Oriented Principles	5	15.9
14	2.5.4	High Speed Data Transfer	4	15.7
15	2.1.2	Distributed Communication Technology	10	15.5
16	2.3.3	Scientific and Engineering Modeling	39	15.4
16	2.5.5	Massive Parallel Processing	1	15.4
18	2.5.8	Expert Systems	6	14.9
18	2.2.1.1	Model Management Tools	12	14.9
20	2.5.1	Computer Processing Speed	2	14.8
21	2.3.4	System Dynamics	3	14.7
21	2.5.3	Desktop M&S	2	14.7
23	2.3.2	Environmental Modeling	6	14.2
24	2.5.7	Knowledge Compendium Tools	5	13.2

Rankings of Taxonomy Subcategories when the 38 M&S Projects are not combined with the 93 Enabling Technologies. Since the main goal of this project was to highlight areas of simulation enabling technology push which should be of high interest to the Air Force, and not to develop investment recommendations about individual M&S projects that use enabling technologies, we felt it was also important to rank the taxonomy categories and subcategories by using just the "pure" enabling technology survey responses we received. This ranking approach allowed us to concentrate on the ETs, which are more important to us in developing investment recommendations than are the M&S Projects. Following are the taxonomy rankings when the 38 projects are taken out of the spreadsheet shown in Appendix C.

Rank	Taxonomy Category or Subcategory		Number of "Pure" ETs in in Category or Subcategory	Average Rating Score Across Category or Subcategory
1	2.3.1	Human Modeling	4	17.4
2	2.2.1.4	Data Acquisition and Insertion	5	17
3	2.2.1.2	Resolution and Validation Management Tools	17	16.9
4	2.1.1	Modeling and Simulation Architecture	8	16.7
5	2.4.1	Design, Manufacturing and Support Technology	2	16.5
6	2.2.1.1	Model Management Tools	6	16.4
7	2.4.4	Virtual Reality Technology	5	16.3
8	2.2.1.3	Simulation Design/Experimental Frame Methodology	9	16.2
8	2.4.5	Simulation Paradigms	31	16.2
10	2.2.2	Hierarchical Simulation	20	16.1
10	2.5.7	Knowledge Compendium Tools	5	16.1
10	2.3.5	Model Abstraction	16	16.1
14	2.4.2	Exercise Management	3	16
14	2.4.3	Man-in-the-Loop	5	16
16	2.5.6	Object-Oriented Principles	5	15.9
17	2.3.2	Environmental Modeling	1	15.7
17	2.3.3	Scientific and Engineering Modeling Methods	21	15.7
17	2.5.4	High Speed Data Transfer	3	15.7
20	2.5.5	Massive Parallel Processing	1	15.4
21	2.1.2	Distributed Communication Technology	6	15.1
22	2.5.8	Expert Systems	6	14.9
23	2.5.1	Computer Processing Speed	1	12.6
24	2.3.4	System Dynamics	0	0
24	2.5.2	Computer Storage and Retrieval	0	0
24	2.5.3	Desktop Modeling & Simulation	0	0

In discussing our ratings and our recommendations about which ET subcategories have the best chance of making a significant impact on the AF, we have decided that all of the top ten rankings are worthy of consideration, with one exception. We do not feel that "Data Acquisition and Insertion" is of great enough significance to merit additional attention even though the average score of the five ETs that fell into this subcategory was relatively high. In this case, the team's general experience in M&S outweighed the sum of ratings which we gave to the five ET examples of "Data Acquisition and Insertion" which were collected in the survey.

The reader will note that the average rating scores for the top ten ranked ET subcategories is only slightly higher than the average rating scores for the next ten. There is not a natural clear cut-off score that appears in the rankings. We chose to recommend the ten ET subcategories that we have because we want to keep the number of recommendations we make to senior-level AF officials at a manageable number. Based on that desire, we feel that ten taxonomy subcategories will probably be about the most subcategories to which additional attention can be devoted.

Composite Scores for Individual Enabling Technologies/Projects

The spreadsheet at Appendix C shows the combined score for each ET or Project under the column heading called "Composite Score." These composite scores were developed by adding the sum for the six rating factors. The highest possible composite score is 26 (four scales had a possible maximum score of 5; two scales had a possible maximum score of 3). The ten ETs and Projects which received scores of 18 or above are:

#7 Model Abstraction
#10 Variable Resolution Modeling, Mixed Fidelity Simulation
#16 Simulation Query Language for Knowledge-Based System
#17 Significant Event Detection in Discrete Environment
#18 Automatic Model Verification
#21 Hierarchical Simulation and Statistical Fidelity
#37 Seamless Universal Voice Interchange System
#52 Generative Analysis
#108 Vestibular System Modeling
#129 Microlaser-based projection display for simulation

Only #37, Seamless Universal Voice Interchange System, is a project. The rest of the top ten individual survey responses are "pure" enabling technologies.

Results - Top Six Ratings for each Rating Scale

1. Importance of the ET or M&S project to the Air Force. Following are the ETs and Projects which received the highest combined ratings across the raters.

Note: The higher the rating, the more the raters believed that the technology is important to the Air Force.

	Rating
- Collaborative Virtual Prototyping (#86)	4.4
- J-MASS Extensions for DoD HLA Interoperability (#90)	4.1
- Modeling, Simulation, and Analysis Support to Aerospace Research and Acquisition (#115)	4.1
- Dynamic Simulation Model of Complex Business System (major defense acquisition system) (#55)	3.9
- Human Performance Modeling (#62)	3.9
- High Performance Computing (#50)	3.8
- Real-Time Piloted Engineering Flight Simulation (#119)	3.8

2. Maturity of the Enabling Technology or M&S Project

Note: The higher the rating, the less the raters believed the technology is mature.

- Seamless Universal Voice Interchange System (#37)	4.8
- Infrared Countermeasures Modeling (#92)	4.6
- Vestibular System Modeling (# 108)	4.3
- Significant Event Detection in Discrete-Event Simulation (#17)	4.3
- Advanced M&S Environments for Intelligent and Cognitive Systems (#22)	4.3
- Generative Analysis (#52)	4.3

3. Potential for Further Development of the Enabling Technology or M&S Project with More Investment

Note: The higher the rating, the more the raters believed there is potential for development with additional work.

- Desktop Modeling and Simulation (# 85)	4.4
- Model Abstraction (#7)	4.3
- Collaborative Virtual Prototyping (#86)	4.1
- Designing Virtual/Live/Constructive Simulation Experiments (#103)	4.0
- Human Performance Modeling (#62)	4.0
- Attributes Extrapolation under High Level Architecture (#12)	4.0

4. The Location of the ET or M&S Project on a Pure Science to Pure Application Continuum

Note: The raters gave higher ratings to the project which they believed had been, or might be, developed more for scientific purposes than application purposes:

- Automatic Model Verification (#18)	4.6
- Simulation Query Language for Knowledge-based Systems (#16)	4.3
- General Information Theory (#28)	4.2
- Advanced M&S Environments for Intelligent and Cognitive Systems (#22)	4.0
- Unified Framework for Design and Implementation of Discrete Event Systems (#15)	4.0
- Cognitive Modeling (#99)	3.9

This science-applied rating scale was particularly important to the team. Despite a number of efforts, we were not able to develop a consensus opinion about a good definition for "enabling technology." As the project developed, it became clear that what was considered an enabling technology by one team member might not necessarily be considered an enabling technology by other team members. Some of the ETs that were reported in the survey seemed to be clearly pure applications to most of the team members, but other team members saw instances where these applications might enable a larger application. In that case, argued some team members, the ET should be considered an enabling technology.

We finally decided to avoid this conundrum by constructing this science-applied scale. This approach allowed each team member to determine for themselves where they believe an ET falls on the science-applied continuum without having to get agreement from all the other team members. Once we agreed to use this scale, we decided not to argue about eliminating any ET simply because some team members might have felt it was not really an ET, but rather an application. For this reason, all ETs which were reported to us via survey were kept in the analysis and are reported in Appendix C.

5. Activity Level on ET or M&S Project

This scale was from 1-3. The higher the previous and current activity in an ET or Project, the lower the score. Thirty-six ETs were given scores of 3, meaning the raters believed these ETs or Projects had not previously had, or presently have, high levels of activity. Therefore, these ETs may be worthy of consideration of increased attention. Standard deviations on a 3-point scale were not deemed to be meaningful and therefore are not reported in Appendix C.

6. Uniqueness of the ET or M&S Project to the Military or AF

There were 18 ETs/Projects which were deemed to have "high uniqueness to the military or AF." Should AF decision makers decide that uniqueness is an important factor in determining ETs or Projects which are good candidates for more attention, those 18 deserve special consideration. It is interesting to note that none of the ETs or Projects which received scores of 3 on the "activity-level" scale, also received scores of 3 on the "uniqueness to the military or AF" scale. This result is not surprising when we consider that any ET or Project which is truly unique to the military would probably already have been receiving some investment. None of the ET or Projects which received composite scores of 18 and above received scores of 3 on the "uniqueness to the military or AF" scale.

3.3 CONCLUSIONS

Obviously, simply because an M&S subcategory or ET or M&S Project received a relatively high composite score does **not** necessarily mean that the AF should make a larger investment. This may be true for a number of reasons. For example, the AF may decide that, given past or current high levels of investment in the subcategory or ET or Project, as described in our "activity" rating criterion, it would not be wise to invest even more funds in that activity. "High Performance Computing," which received a high composite score for individual ETs or Projects is a good illustration of that point. High Performance Computing is already receiving large amounts of funding from the AF and many other sources, both inside and outside the military. It may not make sense for the AF to invest even more Science and Technology funds in High Performance Computing.

There are a number of examples of individual ETs or Projects which received a relatively high composite score but, due to the priorities of AF leaders, may not be good candidates for additional AF investment. For example, "Simulation Query Language for Knowledge-Based Systems" (ET or Project #16) received a composite score of 18.5, but the raters generally determined that its military/AF uniqueness is low. Therefore, it may not warrant additional investment because the raters felt its uniqueness to the military was low. AF decision makers may decide to invest additional resources only in those ETs which are clearly unique to the military with the rationale that limited investment budgets warrant investing only in ETs that are unlikely to be funded from outside the AF. The main point is that the Ad Hoc team's ratings may be of assistance to high-level AF decision makers in making investment decisions, but we see our ratings as only being one input to those decisions. Specific decision-making criteria will have to be determined by those high-level AF decision makers.

It is interesting to note that there was only one individual ET or Project which appeared in the top six list of more than one numerical rating category (that ET being "Human Performance Modeling"). We believe this relative lack of agreement across the top six ETs or Projects of the four numerical categories merely points up the need for multiple rating factors when examining the ET or Project.

Finally, most of the individual M&S ETs or Projects reported in this survey either have been funded by the AF in full or part, or are receiving funding from the AF now. This is not surprising when one considers that the team was made up of personnel from the AF laboratory communities. We sent surveys to those we knew have been working in the M&S ET or Project arena, many of which have been receiving AF funding. We also sent many surveys to individuals and organizations that have not been receiving AF funding. We were less than satisfied with the response from these non-AF funded individuals and organizations. Despite repeated efforts to increase the response rate from these sources, we were not particularly successful. Also, we did not receive any responses from the Army or Navy. We are convinced that there should be continuing efforts to capture data from more sources away from the AF sphere.

4.0 RECOMMENDATIONS OF THE WORKING GROUP

Based upon the team's M&S experience and the analysis described in this report, we offer the following set of recommendations to senior AF leaders:

4.1 RECOMMENDATION 1

Based on the Ad Hoc Team's initial analysis, the following ten subcategories are proposed as M&S enabling technology focus areas which should be reviewed and matched against technology needs by the M&S user/developer community in order to lay the foundation for an M&S research agenda:

Human Modeling;
Resolution and Validation Management Tools;
Design, Manufacturing, and Support Technology;
Model Management Tools;
Virtual Reality Technology;
Simulation Design/Experimental Frame Methodology;
Simulation Paradigms;
Hierarchical Simulation;
Knowledge Compendium Tools; and
Model Abstraction.

Other subcategories of ETs may warrant attention due to particular technology needs, but we strongly believe that the ten subcategories we have identified offer high potential technological benefit for AF modeling and simulation applications.

Rationale for the Team's Enabling Technology Recommendations

Human Modeling - Psychologists have been actively engaged in defining the parameters of human cognition and behavior through decades of research. A considerable amount of this research has been funded by the military. Despite the large volume of empirically and analytically derived data on how humans function cognitively and physiologically, there remains considerable work to be done to make much of this information usable for Air Force purposes, and to fill significant gaps in the modeling of human behavior.

The Air Force's increased reliance on quality large-scale simulation capabilities, especially constructive wargame models, now requires better, more complete human models than we currently have. Constructive wargame models make numerous assumptions about human behaviors, capacities, and reactions to stressful combat situations. Most of these assumptions are based merely on designers' best guesses and, in many cases, human behaviors, capacities, and reactions are not modeled at all. For example, fatigue is an important factor in determining the combat effectiveness of a force. While there has been a fair amount of research data generated that shows fatigue curves for various mental and physical tasks over time, most constructive wargames have not taken this data into account. Many wargames assume that a combat force will be as fresh at the end of a week of combat as it is at the beginning of that week. There are a

variety of human behaviors and decision making under stress capabilities about which we know little. An example is the capability to model a warfighter's level of aggressiveness. There are large individual differences in this variable but we do not know how to measure it well, and the simulation community has never been able to model it. Obviously, if we cannot model aggressiveness for individual warfighters, we are not able to model an entire unit's aggressiveness level.

Industry Recommendation: The following input came to us from the Defense Modeling and Simulation Office (DMSO) Industry Group which reviewed a draft of this report:

"While we agree that Aggressiveness is hard to predict for individuals, behavioral science says it is not as hard to do on a force-by-force basis. Such estimates can be based on observed actions in past battles and related psychological evaluations. Force aggressiveness need not be built up from individual aggressiveness. For example, 'soft factor' estimates are now being made for ground forces by the National Ground Intelligence Center (NGIC). Similar estimates for various air forces should be able to be made by the National Air Intelligence Center or another appropriate agency.

Industry also recommends expanding the list of 'soft factors' to be evaluated as part of the simulation. Training level/readiness and experience are key elements that should be added to the list. Pilots with combat experience or training equivalent to 'Red Flag' certainly rank higher in capability than those without it."

As the military relies increasingly on quality constructive models for analysis, training, doctrine development, test and evaluation, and other functions, it is imperative that our human models grow in number and validity. Investment should be made in modeling the data that exist, and in developing new data for human characteristics that have received little research attention (e.g., measures of warfighter aggressiveness). There is no real reason to believe this funding will come from outside the military. Funding for Government agencies like the National Science Foundation have not kept pace with inflation, and it is not reasonable to expect nondefense industry to launch major efforts in human modeling. Therefore, increased Air Force funding in human modeling is crucial.

Resolution and Validation Management Tools - Resolution and validation management (especially as it pertains to run-time changes in fidelity), while fairly immature, has enormous potential benefits to the simulation and acquisition communities. An important capability of the next generation of Simulation Support Environments should be the ability to selectively declare the level of fidelity of the models, databases, and simulation components that will make up the simulation. In addition, the capability to retrieve appropriate software from a Virtual Model Repository is important. While the declaration of desired component fidelity would occur as a simulation setup process, there is also a need for resolution management at run-time. Dynamic Resolution Management, as we define it, refers to the fact that at certain stages of the simulation, it makes sense to transition from modeling an entity or process at one level of fidelity to representing it at another. Exactly when such a transition is to take place could be either scripted or, more likely, could be dynamically deduced using a new concept called Significant Event Detection. There has been some AF funding expended to date in this area. However, the sums invested have not been large. While it is true that resolution and validation management is an unproved concept, it is the opinion of this Working Group that the Air Force should make an investment to investigate and apply this ground-floor technology.

Industry Recommendation: The following input came to us from the DMSO Industry Steering Group:

"The pursuit of multi-resolution modeling appears worthwhile, especially if it can be made dynamic, i.e. the more detailed representation occurs according to some set of rules or under user command. However, it should not be implied that greater resolution is necessarily synonymous with increased accuracy as we tend to get mixed results with a variety of resolutions being played and sometimes the details obscure the basic process. The key appears to be closely matching the resolution of simulation objects that are interacting heavily with one another. The Military Operations Research Society (MORS) held a mini-Symposium in late February 1997 to discuss multi-resolution modeling. One of the hottest topics was the assertion that increased resolution (precision) did not necessarily equate to increased fidelity (accuracy or 'truth'). It was agreed that the much of the simulation community freely interchanges the terms, but this current study reported here should be careful not to propagate that error since it does not do so in other sections of the study.

It may also be useful to examine the results of the Army Synthetic Theater of War--a program out of the Simulation, Training and Instrumentation Command (STRICOM). In this program, the wargame is disaggregated under both rules and human commands for the purpose of increased fidelity of certain types of engagements, e.g. manned simulators against computer-generated forces, air defense sites against aircraft, increased target area resolution, individual combat at the platform level, special operation representation, special process representation (such as mine clearing), etc.

Another disaggregation effort has been underway for some time is the DARPA Joint Precision Strike Demonstration (JPSD). In this program, the Army EAGLE model disaggregates units into ModSAF to examine the applicability of precision guided weapons in deep strikes."

<u>Design, Manufacturing, and Support Technology</u> - Integrated models and simulations have two main advantages: providing an overarching system or enterprise optimization, and providing a faster throughput. Their final product serves a higher level decision. Design, manufacturing, and support functions have traditionally been stovepipes that are not integrated. The overall product/process may be improved by interface technology. Also, integrated system modeling allows organizations to more easily collaborate on common project developments.
While nondefense industry has an interest in this type of technology, it has not been investing much funding in the development of these tools. The military cannot afford to wait for these tools to slowly evolve. The DoD's future attempts at integrating design, manufacturing, and support on large weapons system procurements require quality M&S tools to aid in this function. Increased AF investment in this technology area should have long-term benefit as integration becomes more critical to acquisition program success.

<u>Model Management Tools</u> - A Model Management System, in its most elemental form, is to a Model Base what a database management system is to a database. It eases, and to some extent automates, the user's ultimate model selection. In addition to standard database functionality, it should also include tools for resolution and validation management, as well as an expert system to help guide the simulation user towards the most appropriate models to suit the purpose of his or her study. The idea of a Model Management System comes from the domain of Decision Support Systems in general, and investment to this point has been primarily from the business world. The Model Management System envisioned by this group should be thought of as an integral front-end component to the Air Force M&S Resource Repository, described in the AF Secretary's and Chief of Staff's "A New Vector" document of 1995. Increased investment in this area will help make the Resource Repository a reality in an earlier time frame than presently envisioned.

Virtual Reality (VR) Technology - These technologies help to create synthetic environments for a variety of purposes. The last few years have seen substantial progress in the development of affordable visual image generators, visual displays, haptic displays, data-based development tools, and a number of other enabling technologies for creating realistic synthetic environments. While the military's investment has aided the progress of these enabling technologies, it is nondefense industry which has been the largest driver. We expect substantial investment from nondefense industry in the years to come, especially from the entertainment industry. There are, however, certain functional areas in which only the military requires significant improvements in VR technology. Since there is little nondefense interest in these areas, progress will only come from military investment. Here are some examples:

- Any latency delays can cause VR users to make errors in their inputs to the VR devices. This latency may not make a difference in an entertainment setting, but it could be disastrous in a military setting. For example, a military operator may be using a manipulator glove from a distance that results in a latency delay. In that case, predictor algorithms need to be built into the software that will prevent the actual manipulation device from putting too much pressure on the object being handled, thus avoiding possible damage to the object.

- The military is the primary user of night vision devices, including goggles and infrared instruments. Law enforcement also makes use of these devices, but it does not have a very large R&D budget. Nondefense industry will probably never be interested in investing money to improve night vision virtual reality technology because there is no market other than defense and law enforcement. Therefore, improvements in night vision simulation will have to come almost purely from military investment.

- The Air Force is intent on vastly improving the capabilities of Uninhabited Aerial Vehicles (UAVs). Currently, UAV operators "fly" the UAV using small visual displays and desktop control sticks. Experience has shown that for UAVs to be operationally responsive, especially high performance UAVs, the operators will need much better tools for improving their situational awareness. This may include more fully immersive visual and haptic displays. The investment for this enabling technology VR development will need to come largely from the military since there are not similar requirements for such highly immersive and responsive user interface tools in industry or entertainment. The need for 360-surround visuals will be a crucial element for true situational awareness to be achieved.

Simulation Design/Experiment Frame Methodology - Investment in these areas has been piecemeal and unfocused, with virtually every agency and service devising its own "standard" simulation support environment; funded primarily with money taken out of the hide from specific applications. This approach, which has unfortunately been the norm in enabling technology research to date, has afflicted the technology area of simulation design/experiment frame methodology. A systematic AF investment in this area will have long-reaching effects in the M&S community. The Working Group does not expect academia or nonDoD industry to increase their levels of funding in this domain, which has been minimal to the present.

Simulation Paradigms - More research into new simulation paradigms is needed as it becomes more obvious that traditional paradigms have become woefully inadequate for an

expanding class of simulation studies. While some alternative paradigms have already received substantial funding and treatment in the literature (e.g., Object-Oriented Simulation, Parallel and Distributed Simulation), there are a good many more areas where promising research is just beginning or needs additional application. These include Qualitative/Fuzzy Simulation; Generative Analysis; Multimodeling and Multifaceted Modeling; paradigms based on Petri Nets and Neural Nets; Concurrent Simulation; Hierarchical Simulation and Mixed Fidelity Simulation; and Web-Based Simulation, to name a few.

In particular, traditional paradigms are not sufficient for providing real-time decision support to the simulation user; having been designed for extensive "controlled variation" experiments, and days or weeks of data reduction and analysis, generally for the purpose of optimization. Today's battle managers are not so much concerned with the "optimum" answer--which generally comes too late anyway--as they are with getting a range of "optimal" answers--where "cardinality" gives way to "ordinality." This requirement for real-time decision support is less pronounced for industry and academia than it is for the military, and less for ground-based military applications than it is for air- and space-based problems. Paradigm research is a very important enabling technology area that holds much promise for ameliorating the problem of real-time decision support. For these reasons, we recommend increased resources for simulation paradigm work.

Industry Recommendation: The following input came to us from the DMSO Industry Group's review of a draft of this report:

"Industry generally agrees (with the Simulation Paradigm recommendation). One interesting piece of work noted in the simulation community recently that was not mentioned in the current study is that of Dr John Gilmer of Wilkes University. He has developed an Measures of Effectiveness (MOE) driven multitrajectory modeling technique that allows many threads/paths to be followed through a simulation's decision points. Those contributing most to the selected MOE are maintained and the others are pruned. This approach provides the equivalent of many simulation runs, but implies a goal seeking agent which generally identifies a more "optimistic" outcome than a simple random selection would provide. It also reduces the number of runs needed to produce statistically valid results."

Hierarchical Simulation - Hierarchical Simulation is the basis for a tremendous amount of activity in the research community, as people become more attuned with the problems of adapting existing monolithic simulation systems, and the opportunities afforded by advances in software reuse and model interoperability standards. For the most part, it is currently in the early stages of implementation, prototyping, and testing. As it matures, Hierarchical Simulation should contribute greatly to the construction of simulations that are more realistic (i.e., accurate), useful (i.e., timely), and reusable (different studies can be set up merely by refocusing on a new segment of the system to amplify, as opposed to completely developing a new simulation).

The Air Force is committed to the general concept of Hierarchical Simulation, as evidenced by the adoption of the multitiered "Hierarchy of Models," and their hierarchically based program initiatives (e.g., JSIMS, JWARS, J-MASS, etc.). Many millions of dollars are currently programmed for, or have already been spent on, the lofty goal of an integration of models and simulations at varying levels of the hierarchy. The ultimate plan is for models and simulations at the various levels in the hierarchy to be able to be reused and interconnected with models and simulations at other levels in the hierarchy (e.g., platform-level models can be interfaced to air-to-air engagement simulations, etc.).

Additional development of Hierarchical Simulation enabling tools could provide increased connectivity of models and simulations without the added run-time that current approaches require.

Knowledge Compendium Tools - Air Force systems and system support elements are often complex and in a continual state of upgrade or replacement. The abilities of knowledgeable, skilled people are essential to their successful employment and development. New people, hired or transferred, acquire much of the knowledge through the mentoring process, if it is possible. Service personnel downsizing could destroy, damage, or delay the success of such AF systems. Hence the use of dynamic learning tools, Knowledge Compendiums, has the role of supplementing the mentoring process. Critical applications should be determined on a case-by-case examination of who and what is being eliminated, and how rare and complex are the disciplines. We have been surprised at the relatively small investments in this important area from academia and nonDoD industry. We believe the cost-benefit of AF attention in this area would be very positive.

Industry Recommendation: The following input came to us from the DMSO Industry Group's review of a draft of this report:

"This is considered by industry to be an area of great importance where the Air Force should seek matching funding from national resources such as the National Science Foundation. It is truly a dual use technology."

Model Abstraction - The hierarchy of models, as a conceptual framework, is a sound idea. The ultimate plan is for models and simulations at the various levels in the hierarchy to be able to be reused and interconnected with models and simulations at other levels in the hierarchy (e.g., platform-level models can be interfaced to air-to-air engagement simulations, etc.). The idea stems from the desire to increase the level of fidelity and accuracy in these higher level simulations (e.g., air-to-air engagement) by incorporating the accuracy of the detailed models. This desire occurs because simulation users, battle managers, or other real-time decision makers need the most accurate answer they can get in the time they need it.

However well intentioned, model integration as a way of increasing realism is not, in our opinion, the answer. For every model that gets interfaced to, or integrated with, another simulation, the run-time has to increase. It is impossible for this increase not to occur. This is especially true considering that there are some extremely accurate engineering-level models at the lowest level of the pyramid that could ultimately be invoked at the theater-level. These models could be run in place of their rudimentarily modeled counterparts in that simulation. What would result would be an extremely accurate answer, but it would be so late as to be completely unusable.

This Working Group believes a better approach would be to mold the essence of the detailed simulation codes into a form that is compatible with the aggregate simulation in terms of level of complexity, and connect that version to the larger simulation. This field of research is called Model Abstraction. There are many techniques for accomplishing this goal. Each technique has its own "best" domain of applicability. It is an off-line activity in which the behavior of a detailed model is captured into a new, reduced form. Examples of this approach are: a mathematical metamodel, a lookup table, performance curves, and response surfaces. The

abstracted model's output is statistically "close" to that of the detailed model, without the run-time complexity of that detailed model. The result of this approach would be the production of accurate results in real time. We wish to dispel the notion that model reuse means that the existing legacy code itself has to be reused.

Model Abstraction is probably the most important enabling technology area in simulation science today. The requirements for mixed fidelity composition, for representing models at varying degrees of resolution, and for reducing the complexity of monolithic legacy code are widely stated by all the services. As important is the requirement to infuse large-scale decision support simulations with the accuracy inherent in the vast array of engineering-level models in the Air Force inventory. Model Abstraction is the only way to provide validated accuracy to the decision maker in real time. There is some research under way, using a wide variety of approaches; however, it is a fairly immature discipline, with few actual prototype implementations in place. Nonetheless, the potential benefits of such research to the Air Force, and the DoD in general, are enormous and far-reaching, and it is the feeling of this Working Group that the Air Force would be well served to fund research in this technology area.

Industry Recommendation: The following input came to us from the DMSO Industry Group's review of a draft of this report:

"Industry points out a good example of this abstraction in the DARPA Dynamic Virtual Worlds (Virtual Environments) modeling effort within the Synthetic Theater of War Advanced Concept Technical Demonstration. Physics levels models are being abstracted for specific environments (e.g. COMBIC smoke model in desert terrain) to provide a 'close approximation of the detailed, high resolution' model."

Conclusion to Recommendation 1 Section

Should a Phase II of this effort be conducted, we recommend that the effort be concentrated on these categories. Should the Air Force determine that its M&S S&T position should change to allow investment in M&S enabling technology research, we highly recommend that the enabling technology subcategories which have been highlighted in our "Top Ten" be used as an initial technology thrust proposal, to be reviewed/compared against technology needs priorities established by the M&S user/developer community.

4.2 RECOMMENDATION 2

We recommend that AF/XOM and SAF/AQR continue to discuss possible changes to the current Air Force stance regarding Modeling and Simulation Science and Technology (S&T). For some years the Air Force has held that the Science and Technology community does not perform research and development on M&S for its own sake. The stance stipulates that the only time the S&T community works with new S&T for M&S is when a lab is directly supporting an application area such as manpower, personnel, and training, or radar development. While that position has been useful in the past, it may well be time now to determine if it is still in the Air Force's best interest.

4.3 RECOMMENDATION 3

AF/XOM and SAF/AQR should formulate a plan to keep a "Technology Watch" on a certain number of enabling technologies, many of which are detailed in Appendix D of this report. The Tech Watch would be a formal plan to track in a systematic way those enabling technologies which clearly have a good chance of significantly impacting the Air Force's future M&S efforts.

4.4 RECOMMENDATION 4

In addition to the recommendation above, it may be advantageous to have a data base of enabling technologies developed and maintained by an existing Information Analysis Center (IAC), or perhaps develop a new IAC, if this task is not appropriate for any of the existing IACs. It may be that the Defense Modeling and Simulation Office (DMSO) would be interested in working with the three Services to fund such an effort. In our discussions with DMSO during this study, DMSO has expressed interest in the outcome.

4.5 RECOMMENDATION 5

Finally, we strongly recommend that a Phase II of this M&S enabling technology analysis be directed by AF/XOC and SAF/AQR. We feel the next phase should involve a group external to the AF, made up of M&S experts who may have different contacts and insights than the current Ad Hoc Laboratory team. We believe the AF Scientific Advisory Board would make an excellent choice for Phase II, but there are other alternatives to forming this external group. We have been in contact with members of the Defense Modeling and Simulation Office, and they have expressed a potential interest in helping to sponsor such a Phase II effort.

We also recommend that the new Air Force Material Command Modeling and Simulation Integrated Office be made part of Phase II. Specifically, that office could be asked to develop M&S ET or Project recommendations from the requirements pull side of the investment equation. Phase I has identified many ETs on the tech push side. Until the requirements pull has been clearly identified, it will not be possible to form a reasonable M&S ET or Project investment strategy. The gap between tech push and requirements pull defines the ET or Project need where additional ET or Project investment is required.

APPENDIX A

LTR FROM BG THOMAS CASE (AF/XOM) TO AFMC/ST REQUESTING AN ANALYSIS OF MODELING AND SIMULATION ENABLING TECHNOLOGIES

MEMORANDUM FOR AFMC/ST Jan 1996

FROM: AF/XOM

SUBJECT: New Vector in Modeling and Simulation (M&S)

In order to fully institute the Chief's New Vector in modeling and simulation (M&S) and ensure that the Air Force can reap the benefits and advantages of rapidly advancing M&S-related technologies in the future, we agree that it is essential to recognize and pursue high payoff areas of M&S-related research and development that are relevant to the Air Force. Developments in these technology focus areas should be monitored and where appropriate, the Air Force should stimulate activity and advancement through targeted research and development investment.

Request AFMC/ST conduct a comprehensive review of long-lead M&S-related technologies (both within and outside the USAF) in order to identify those areas that would be of high interest or significance to the USAF for constructive, virtual, live or hybrid simulations, both local and distributed. Particular R&D topic areas or Projects where USAF investment would be warranted should be highlighted.

A six- to nine-month review (emphasizing breadth more than depth) would be appropriate; if necessary, a follow-on effort focusing on selected high interest topics may be requested. The survey should be enough to cover all technical areas which would significantly contribute to USAF M&S future capabilities, covering both hardware and software, with equal or greater emphasis placed on the latter. Suggested hardware areas include processors, input/output devices and methods, man-machine interface, storage, and communications; software topic suggestions include software engineering developments, simulation science, advances in programming concepts, data handling techniques, variable resolution modeling, and intelligent systems.

My staff will be available to assist your project officers to further define and advance this timely and important technology review. AF/XOM point of contact is Mr. Allen Murashige, DSN 227-5795.

---Signed---
THOMAS R. CASE, Brig Gen, USAF
Dir, Modeling, Simulation & Analysis
DCS/Plans & Operations

APPENDIX B: MAJOR ENABLING TECHNOLOGY ORGANIZATIONS AND INDIVIDUALS

ET/Project	Title	Major Players	Other Players
1	Run-Time Adaptive Computer Interfaces	Daniel P. Schiavone, James Hooker, John Prikkel Ball Aerospace and Technologies Corp. 2875 Presidential Dr., Ste 180 Fairborn OH 45324 Tel: (513) 320-4060 Fax: (513) 429-1687 Dschiavone@ball.com	
2	Distributed Simulation Performance Modeling	Daniel P. Schiavone, Donald Bertke Ball Aerospace and Technologies Corp. 2875 Presidential Dr, Ste 180 Fairborn OH 45324 Tel: (513) 320-4060 Fax: (513) 429-1687 Dschiavone@ball.com	
3	Dynamic Structure Modeling and Simulation	Bernard P. Zeigler & Hyup J. Cho ECE Dept., University of Arizona ais.ece.arizona.edu hjcho@ece.arizona.edu http://www-ais.ece.arizona.edu/ Fernando Barros barros@mercurio.uc.pt	
4	Manufacturing Control Based on Discrete Event Simulation	Jerry M. Couretas & Bernard P. Zeigler Dept of Electrical and Computer Engineering University of Arizona Tucson AZ 85721 Tel: (512) 884-5362 couretas@ece.arizona.edu zeigler@ece.arizona.edu	
5	Real-time, Man-in-the-loop Weapon System Simulation	Timothy S. Shaw HRB Systems, Inc. P.O. Box 60 State College, PA 16804-0060 Tel: (814) 238-4311 ext.2068 Tss@icf.hrb.com	George A. Downsbrough HRB Systems, Inc. P.O. Box 60 State College, PA 16804-0060 Tel: (814) 238-4311 ext. 2068 gad@icf.hrb.com
6	Stochastic Layered Modeling	Dr Thomas C. Fall Lockheed Martin Space & Range Systems 1260 Crossman Avenue Sunnyvale, CA 94089-1198 Tel: (408) 734-6458 tfall@srs.loral.com Mary Lou Benhamin Kylix Associates	

ET/ Project	Title	Major Players	Other Players
7	Model Abstraction	Dr. Paul A. Fishwick Dept of Computer and Information Science and Engineering University of Florida Bldg CSE, Room 301 Gainesville, FL 32611 Phone and FAX: (352) 392-1414 fishwick@cise.ufl.edu	Dr Bernard P. Zeigler (Arizona) Don Caughlin (Mission Res. Corp.)
8	Object-Oriented Model Engineering	Dr. Paul A. Fishwick Dept of Computer and Information Science and Engineering University of Florida Bldg CSE, Room 301 Gainesville, FL 32611 Phone and FAX: (352) 392-1414 fishwick@cise.ufl.edu	Dr Bernard P. Zeigler (Arizona) Dr Tag-Gon Kim (KAIST)
9	Web-Based Simulation	Dr. Paul A. Fishwick Dept of Computer and Information Science and Engineering University of Florida Bldg CSE, Room 301 Gainesville, FL 32611 Phone and FAX: (352) 392-1414 fishwick@cise.ufl.edu	
10	Variable Resolution Modeling, Mixed Fidelity Simulation	Fred Frantz NYSTEC 28 Electronics Parkway Rome, NY 13441 315-338-5818 frantz@syrres.com	Dr Paul Fishwick, University of Florida Dr Bernard Zeigler, University of Arizona
11	Small Team Situational Training and Mission Planning/Rehearsal	Dr Norman Badler, University of Pennsylvania Dr Mike Zyda, Naval Postgraduate School	Dr Sharon Stansfield Sandia National Laboratories P.O. Box 5800, MS0978 Albuquerque NM 87185-0978 Tel: (505) 844-1396 Fax: (505) 844-2057 sastans@sandia.gov

ET/ Project	Title	Major Players	Other Players
12	Attributes Extrapolation under High Level Architecture (HLA)	Dr Kurt Lin Associate Professor of Aerospace Engineering Institute for Simulation and Training 3280 Progress Drive Orlando FL 32826 Tel: (407) 658-5029 Klin@pegasus.cc.ucf.edu Mr Mikel D. Petty Program Maanger Institute for Simulation and Training Tel: (407) 658-5022 mpetty@ist.ucf.edu	
13	Distributed Simulation of Heterogeneous Models	Dr Tag Gon Kim Department of Electrical Engineering Korea Advanced Institute of Science and Technology Taejon 305-701, Korea Tel: +82-42-869-3454 tkim@ee.kaist.ac.kr	
14	Database Support for Simulation Model	Dr Tag Gon Kim Department of Electrical Engineering Korea Advanced Institute of Science and Technology Taejon 305-701, Korea Tel: +82-42-869-3454 tkim@ee.kaist.ac.kr	
15	Unified Framework for Design and Implementation of Discrete Event Systems	Dr Tag Gon Kim Department of Electrical Engineering Korea Advanced Institute of Science and Technology Taejon 305-701, Korea Tel: +82-42-869-3454 Tkim@ee.kaist.ac.kr	
16	Simulation Query Language for Knowledge-Based Systems	Christos G. Cassandras Dept of Electrical and Computer Engineering University of Massachusetts Amherst MA 01003 Tel: (413) 545-1340 cassandras@ecs.umass.edu Wei-Bo Gong Dept of Electrical and Computer Engineering University of Massachusetts Amherst MA 01003 Tel: (413) 545-0384 gong@ecs.umass.edu	

ET/ Project	Title	Major Players	Other Players
17	Significant Event Detection (SigEvD) in Discrete-Event Simulation	Sankait Vahie & Bernard P. Zeigler AI & Simulation Labs Dept of Electrical & Computer Engrg, Univ of Arizona Tucson, AZ 85721 Tel: (520) 621-2108/6184 Sankait@ece.arizona.edu ziegler@ece.arizona.edu	
18	Automatic Model Verification	Dr Tag Gon Kim Department of Electrical Engineering Korea Advanced Institute of Science and Technology Taejon 305-701, Korea Tel: +82-42-869-3454 tkim@ee.kaist.ac.Kr	
19	Experimental Frame Methodology	Bernard Zeigler Electrical and Computer Engr University of Arizona Tucson AZ 85721 Tel: (520)-621-6184 Fax: (520)-621-3862 http://www-ais.ece.arizona.edu/-hessam	
20	Graphical Description of Discrete Event Models Behavior	Dr Tag Gon Kim Department of Electrical Engineering Korea Advanced Institute of Science and Technology Taejon 305-701, Korea Tel: +82-42-869-3454 tkim@ee.kaist.ac.kr	
21	Hierarchical Simulation and Statistical Fidelity	Christos G. Cassandras Dept. of Electrical and Computer Engineering University of Massachusetts Amherst MA 01003 Tel: (413) 545-1340 cassandras@ecs.umass.edu Wei-Bo Gong Dept of Electrical and Computer Engineering University of Massachusetts Amherst MA 01003 Tel: (413) 545-0384 gong@ecs.umass.edu	

ET/ Project	Title	Major Players	Other Players
22	Advanced M&S Environments for Intelligent and Cognitive Systems	Mike Young Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/HRGA 2696 G Street Wright-Patterson AFB OH 45433-7605 Bolt, Baranek & Newman (BBN) Systems & Technologies Inc. Cambridge MA Sankait Vahie & Bernard P. Zeigler AI & Simulation Labs Dept of Electrical & Computer Engineering University of Arizona Tucson AZ 85721 Tel: Office (520)621-2108 Tel: Lab (520) 621-6184 Sankait@ece.arizona.edu zeigler@ece.arizona.edu	
23	Neural Networks for Metamodeling	Christos G. Cassandras Dept of Electrical and Computer Engineering University of Massachusetts Amherst MA 01003 Tel: (413) 545-1340 cassandras@ecs.umass.edu Wei-Bo Gong Dept of Electrical and Computer Engineering University of Massachusetts Amherst MA 01003 Tel: (413) 545-0384 gong@ecs.umass.edu	
24	Rational Functions in Metamodeling	Christos G. Cassandras Dept of Electrical and Computer Engineering University of Massachusetts Amherst MA 01003 Tel: (413) 545-1340 cassandras@ecs.umass.edu Wei-Bo Gong Dept of Electrical and Computer Engineering University of Massachusetts Amherst MA 01003 Tel: (413) 545-0384 gong@ecs.umass.edu	

ET/ Project	Title	Major Players	Other Players
25	Fuzzy Discrete Event Systems M&S	Dr Tag Gon Kim Department of Electrical Engineering Korea Advanced Institute of Science and Technology Taejon 305-701, Korea Tel: +82-42-869-3454 Tkim@ee.kaist.ac.kr	
26	Inductive Modeling/Soft Computing	Hessam S. Sarjoughian Electrical and Computer Engr. University of Arizona Tucson, AZ 85721 Tel: (520) 621-6184 Fax: (520) 621-3862 hessam@ece.arizona.edu http://www-ais.ece.arizona.edu/~hessam Thomas G. Dietterich Computer Science Department Oregon State University Corvallis OR 97331 Tel: (541) 737-5559 Fax: (541) 737-3014 Tgd@cs.orst.edu George G. Klir Systems Science and Industrial Engr. SUNY at Binghamton Binghamton NY Tel: (607) 777-6509 rocha@Binghamton.edu Francois E. Cellier Electrical and Computer Engr. University of Arizona Tucson AZ 85721 Tel: (520) 621-6192 cellier@ece.arizona.edu	

ET/ Project	Title	Major Players	Other Players
27	Fuzzy Systems	Cliff Joslyn NRC Research Associate NASA Goddard Space Flight Center Greenbelt MD 20771 USA Tel: (301) 286-5773 joslyn@kong.gsfc.nasa.gov http://gwis2.circ.gwu.edu/~joslyn	Others are discussed in the write-up for this ET/Project in Appendix D
28	General Information Theory (GIT)	Cliff Joslyn NRC Research Associate NASA Goddard Space Flight Center Greenbelt MD 20771 USA Tel: (301) 286-5773 joslyn@kong.gsfc.nasa.gov http://gwis2.circ.gwu.edu/~joslyn	Prof George Klir: http://ssie.binghamton.edu/people/klir.html
29	Fuzzy Modeling	H. John Caulfield Univ Eminent Scholar, Dept of Physics P.O. Box 1268 Alabama A&M University Normal AL 35762 Tel: (205) 851-5870 caulfield@caos.aamu.edu J. Ludman Northeast Photosciences 71053.3526@compuserve.com B. Kosko University of Southern California. kosko@sipi.usc.edu	
30	Model Simplification through Formalism Transformation	Bernard Zeigler, Electrical and Computer Engr. University of Arizona Tucson AZ 85721 Tel: (520) 621-6184 Fax: (520) 621-3862 Dr Tag Gon Kim Department of Electrical Engineering Korea Advanced Institute of Science and Technology Taejon 305-701, Korea Tel: +82-42-869-3454 tkim@ee.kaist.ac.kr Ghi Vansteenkiste University of Ghent - Belgium	

ET/ Project	Title	Major Players	Other Players
31	Parallel Simulation; The Use of Parallel and Distributed Platforms to Execute Discrete and Continuous Simulations	David Nicol Dept of Computer Science Dartmouth College Hanover NH 03755 nicol@cs.dartmouth.edu Richard Fujimoto School of Computing Georgia Tech Atlanta GA 30332 fujimoto@cc.gatech.edu Rajive Bagrodia Dept of Computer Science UCLA Los Angles CA bagrodia@cs.ucla.edu	
32	High Performance Parallel Discrete Event Simulation	Doohwan Kim and Bernard Zeigler Dept of Electrical and Computer Engineering University of Arizona Tucson AZ 85721 Tel: (520) 621-6184 dhkim@ece.arizona.edu zeigler@ece.arizona.edu	
33	Concurrent Simulation	Christos G. Cassandras Dept of Electrical and Computer Engineering University of Massachusetts Amherst MA 01003 Tel: (413) 545-1340 cassandras@ecs.umass.edu Y.C. Ho Division of Applied Science Harvard University Cambridge MA 02138 Tel: (617) 495-3992 ho@paone.harvard.edu	Wei-Bo Gong Dept of Electrical and Computer Engineering University of Massachusetts Amherst MA 01003 Tel: (413) 545-0384 gong@ecs.umass.edu

ET/ Project	Title	Major Players	Other Players
34	Quantification of Fidelity. Relating Simulator Fidelity to Counterpart Operational System Usage	Brian Goldiez Institute for Simulation and Training University of Central Florida 3280 Progress Drive Orlando FL 32826 Tel: (407) 658-5015 bgoldiez@ist.ucf.edu Dr Richard Dunn Naval Air Test Center, Patuxent River, MD Cdr Dennis McBride Naval Research Laboratory, Washington DC	
35	Simulated Environment Interoperability between and among Mixed Fidelity Simulators	Brian Goldiez and Guy Schiavone Institute for Simulation and Training University of Central Florida 3280 Progress Drive Orlando FL 32826 Tel: (407) 658-5000 bgoldiez@ist.ucf.edu or guy@ist.ucf.edu	
36	Physics-Based Sensor Models	McDonnell Douglas and Lockheed Martin are two major players in the area of radar system simulation devices.	
37	Seamless Universal Voice Interchange System (SUVIS)	Scott Smith Institute for Simulation and Training University of Central Florida 3280 Progress Drive Orlando FL 32826 Tel: (407) 658-5531 ssmith@ist.ucf.edu	
38	Computer-Generated Forces	Clark R. Karr Institute for Simulation and Training University of Central Florida 3280 Progress Drive Orlando FL 32826 Tel: (407) 658-5015 ckarr@ist.ucf.edu Mr Anthony Courtrache, SAIC Mr Joshua Smith, Sagacitech Lockheed Martin	

ET/ Project	Title	Major Players	Other Players
39	Three-Dimensional, Stereoscopic, Pseudo-holographic, Real-time Display of Computer-generated Imagery	Scott Smith & Dr Thomas Clarke Institute for Simulation and Training University of Central Florida 3280 Progress Drive Orlando FL 32826 Tel: (407) 658-5531 ssmith@ist.ucf.edu	
40	Multi-Resolution Simulation	Clark R. Karr & Robert Franceschini Institute for Simulation and Training University of Central Florida 3280 Progress Drive Orlando FL 32826 Tel: (407) 658-5052 ckarr@ist.ucf.edu	
41	Embedded Training	Ronald W. Tarr Institute for Simulation and Training University of Central Florida 3280 Progress Drive Orlando FL 32826 Tel: (407) 658-5080 rtarr@ist.ucf.edu Air Force Research Laboratory (formerly Armstrong Laboratory) Army Research Institute University of Massachusetts University of North Carolina US Army (STRICOM) Loral SAIC DARPA Rome Laboratory	
42	After-Action Review (AAR) and Unit Performance Measurement	Seng Tan Institute for Simulation and Training University of Central Florida 3280 Progress Drive Orlando FL 32826 Tel: (407) 658 5534 stan@ist.ucf.edu Dr Larry Meliza and Dr Dave Bessimer Army Research Institute	

ET/ Project	Title	Major Players	Other Players
43	Calendaring via the World Wide Web (WWW)	Tammie McClellan and Robert Reed Institute for Simulation and Training University of Central Florida 3280 Progress Drive Orlando FL 32826 Tel: (407) 658-5000 tmcclell@ist.ucf.edu Netscape	
44	Document Collaboration via the World Wide Web (WWW)	Robert Reed Institute for Simulation and Training University of Central Florida 3280 Progress Drive Orlando FL 32826 Tel: (407) 658-5501 rreed@ist.ucf.edu LOTUS, workgroup collaboration tools Microsoft Netscape Digital Equipment Corporation	
45	Environment Representation in Advanced Distributed Simulation Entity-level, Force-on-force Ssimulations	Mr Richard Schaffer Lockheed Martin Advanced Distributed Simulation 50 Moulton Street Cambridge MA 02138 Mr George Lukes PM Synthetic Environments Defense Advanced Research Projects Agency Arlington, VA Mr Jeff Turner PM Synthetic Environments US Army Topographic Engineering Center Ft Belvior, VA	

ET/ Project	Title	Key Players	Other Players
46	Exercise Management for Distributed Simulations	Dr David Milgram Lockheed Martin Advanced Technology Center M/S: 9610/255 3251 Hanover St. Palo Alto CA 94304 Tel: (415) 424-2277 Fax: (415) 354-5235 milgram@stc.lockheed.com The DIS community has set up a large number of subcommittees to develop standards in this area.	
47	Agent-based Simulations of Complex and Complex-adaptiveSystems	Roger Burkhart Deere & Company Tel: (309) 765-4365 roger@go.deere.com	Bruce Abell 1399 Hyde Park Road Sante Fe NM 87501 Tel: (505) 984-8800 babell@santafe.edu
48	General Object-Oriented Simulation Environment	Capt Todd M. Carrico & Lt John DiPasquale Air Force Research Laboratory (formerly Armstrong Laboratory) Logistics Research Division Wright-Patterson AFB OH 45433-5000 Tel: DSN 785-2606 (513) 255-2606	
49	Representational Resolution and Fidelity	Los Alamos POC: Dr Randy Michelsen Los Alamos National Laboratory MS F602 Los Alamos NM 87545 Tel: (505) 667-0789 Fax: (505) 665-2017 rem@lanl.gov	
50	High Performance Computing	Numerous	Los Alamos POC: Dr Randy Michelsen Los Alamos National Laboratory MS F602 Los Alamos NM 87545 Tel: (505) 667-0789 Fax: (505) 665-2017 rem@lanl.gov

ET/ Project	Title	Major Players	Other Players
51	Software Reuse via Composition	Los Alamos POC: Dr Randy Michelsen Los Alamos National Laboratory MS F602 Los Alamos NM 87545 Tel: (505) 667-0789 Fax: (505) 665-2017 rem@lanl.gov	
52	Generative Analysis	The Sante Fe Institute	Ray Gordon Los Alamos National Laboratory P.O. Box 1663 Los Alamos NM 87545 Tel: (505) 667-2205 rgordon@lanl.gov
53	Model Abstraction Via Solution of the Inverse Problem to Define a Reduced Order Model	Dr Don Caughlin Space and Flight Systems Laboratory 1867 Austin Bluffs Parkway, Suite 202 Colorado Springs CO 80918-7864 Tel: (719) 593-3573 Fax: (719) 548 9127 donc@mozart.uccs.edu	
54	Intelligent Simulation Objects	Ray Gordon Los Alamos National Laboratory P.O. Box 1663 Los Alamos NM 87545 Tel: (505) 667-2205 rgordon@lanl.gov	

ET/ Project	Title	Major Players	Other Players
55	Dynamic Simulation Model of Complex Business System (Major Defense Acquisition Program)	Pugh-Roberts Associates, Cambridge MA 01730 (Mr Kenneth Cooper, President) Mr Chris Hernandez, Manager, Product Definition, Pico Rivera CA F/A-18 Program Dynamics Model Dr J. J. McIlroy Program Director, Program Independent Analysis, F/A-18 Programs, Northrop Grumman Corporation, One Hornet Way, El Segundo CA 90245. Tel: (310) 331-5409 Jmcilroy@world.northgrum.com	
56	Object-Oriented Simulation	Kevin C. Trott, PAR Government Systems Corporation Tel: (315) 738-0600, kevin_trott@partech.com	
57	Human Dynamic Modeling	Dr Louise Obergefell Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/CFBV 2610 Seventh Street Wright-Patterson Air Force Base OH 45433-7901 Tel: (513) 255-3665 DSN 785-3665 lobergefell@al.wpafb.af.mil Dr John B. Bomar, Jr. Biodynamic Research Corporation 9901 IH West, Suite 1000 San Antonio TX 78230 Tel: (210) 691-0281 BOMARJB@brc-sat.mhs.compuserve.com	

ET/ Project	Title	Major Players	Other Players
58	Human Interactive Mission Simulation	Scott L. Smith, Captain, USAF Air Force Research Laboratory (formerly Armstrong Laboratory) AL/CFHD, Bldg 248 2255 H Street Wright-Patterson AFB OH 45433-7022 ssmith@al.wpafb.af.mil Dr Herbert H. Bell Air Force Research Laboratory Warfighter Training Research Division/HEAW 6001 S. Power Road, Bldg 558 Mesa AZ 85206-0904 Tel: (602) 988-6561, DSN 474-6561 bell@hrlban1.aircrew.asu.edu Lt Col Martin Stytz Air Force Institute of Technology/ENG 2950 P Street Wright-Patterson AFB OH 45433-7765 Tel: (513) 255-3576, DSN 785-3576 Mstytz@afit.af.mil	
59	Human Operator Cognitive Modeling for Mixed Level Analysis	Mr Gary B. Reid Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/CFHP 2255 H Street Wright-Patterson AFB OH 45433-7022 Tel: (513) 255-8749, DSN 785-8749 greid@al.wpafb.af.mil Keith Hendy Defense Civil Institute of Environmental Medicine P. O. Box 2000 North York, Ontario Canada Kevin Corker NASA-Ames Research Center	
60	Simulation Design and Evaluation Using Operator State Monitoring	Dr Glenn F. Wilson Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/CFHP 2255 H Street Wright-Patterson AFB OH 45433-7022 Tel: (513) 255-8748, DSN 785-8748 GWILSON@FALCON.AL.WPAFB.AF.MIL	

ET/ Project	Title	Major Players	Other Players
61	Define Visual Display Specifications through Human Performance Simulation	Brian H. Tsou Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/CFHV 2255 H Street Wright-Patterson AFB OH 45433-7022 Tel: (513) 255-8896 DSN 785-8896 Btsou@al.wpafb.af.mil Aerospace Vision Lab Human Engineering Division Air Force Research Laboratory (formerly Armstrong Laboratory) Wright-Patterson AFB OH 45433	
62	Human Performance Modeling	Dr Sam Schiflett Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/CFTO 2504 Gillingham Dr, STE 1 Brooks AFB TX 78235-5104 Tel: (210) 536-3464 DSN 240-3464 schiflett@apache.brooks.af.mil Dr Mike Fineberg Pacific-Sierra 1400 Key Blvd, Suite 700 Arlington VA 22209 Tel: (703) 527-4975	
63	Environmental Molecular Modeling (EMM)	Dr Tom Stauffer Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/EQC 139 Barnes Drive, Ste 2 Tyndall AFB FL 32403 Tel: (904) 283-6059 DSN 523-6059 Tom_Stauffer@ccmail.aleq.tyndall.af.mil Gaussian, Inc. Schrodinger, Inc.	

ET/ Project	Title	Major Players	Other Players
64	Risk Assessment/Dispersion Modeling	Capt Carolyn Vadnais Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/EQ 139 Barnes Drive, Ste 2 Tyndall AFB FL 32403-5323 Tel: (904) 283-6249 DSN 523-6249 Carolyn_Vadnais@ccmail.aleq.tyndall.af.mil ACTA Inc. Yamada Arts and Sciences Kamada Science	
65	Emissions Inventory/Dispersion Modeling	Capt Carolyn Vadnais Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/EQ 139 Barnes Drive, Ste 2 Tyndall AFB FL 32403-5323 Tel: (904) 283-6249 DSN 523-6249 Carolyn_Vadnais@ccmail.aleq.tyndall.af.mil Diana Liang Federal Aviation Administration Office of Environment and Energy Analysis and Evaluations Branch AEE-120 800 Independence Ave SW Washington DC 20591 Tel: (202) 267-3494 dliang@mail.hq.faa.gov	

ET/ Project	Title	Major Players	Other Players
66	Dispersion Modeling	Capt Carolyn Vadnais Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/EQ 139 Barnes Drive, Ste 2 Tyndall AFB FL 32403-5323 Tel: (904) 283-6249 DSN 523-6249 Carolyn_Vadnais@ccmail.aleq.tyndall.af.mil Dr Ted Yamada YSA Corporation, Inc. Rt 4 Box 81-A Santa Fe NM 87501 Tel: (505) 989-7351 ysa@rt66.com	
67	Dispersion Modeling	Capt Carolyn Vadnais Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/EQ 139 Barnes Drive, Suite 2 Tyndall AFB FL 32403-5323 Tel: (904) 283-6249 DSN 523-6249 Carolyn_Vadnais@ccmail.aleq.tyndall.af.mil Dr Milt Teske Continuum Dynamics, Inc. PO Box 3073 Princeton NJ 08543 Tel: (609) 734-9282 x109 milt%cdi@princeton.edu	
68	Decision Support System for Compliance	Capt Carolyn Vadnais Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/EQ 139 Barnes Drive, Ste 2 Tyndall AFB FL 32403-5323 Tel: (904) 283-6249 DSN 523-6249 Carolyn_Vadnais@ccmail.aleq.tyndall.af.mil Mike Kemme Environmental Engineering Division Environmental Sustainment Lab US Army Corps of Engineers Construction Engineering Research Lab (CERL) Tel: (217) 373-4554 m-kemme@cecer.army.mil	

ET/ Project	Title	Major Players	Other Players
69	Optical Radiation Effects Simulation	Ms Christina Richardson TASC, Inc. 750 East Mulberry Ave, Suite 302 San Antonio TX 78212 Tel: (210) 536-3038 Cerichardson@tasc.com Capt Howard Gleason Air Force Research Laboratory (formerly Armstrong Laboratory) Optical Radiation Division 8111 18th Street Brooks AFB TX 78235-5215 Tel: (210) 536-3039 DSN: 240-3039 Howard.gleason@platinum.brooks.af.mil	
70	Space Simulation Framework	Dr Richard K. de Jonckheere Air Force Research Laboratory (formerly US Air Force Phillips Laboratory) Kirtland AFB NM 87117-5776 Tel: (505) 846-5054 Dejonckr@plk.af.mil Ms Terri Franklin Photon Research Associates San Diego CA Tel: (619) 455-9741 Tlf@kirk.photon.com Mr Mark Young Khoral Research Inc. Albuquerque NM Tel: (505) 837-6500 Young@khoral.com Mr Dave Gadd Air Force Research Laboratory (formerly Wright Laboratory) Wright-Patterson AFB, OH Tel: (513) 255-1115 Dgadd@mbvlab.wpafb.af.mil	Dr Richard K. deJonckheere Air Force Research Laboratory (formerly US Air Force Phillips Laboratory) Kirtland AFB NM 87117-5776 Tel: (505) 846-5054 dejonckr@plk.af.mil

ET/ Project	Title	Major Players	Other Players
71	Network-based Distributed Computing Systems	Sun Microsystems	Francis G. McDougall OLAC PL/RKBA 5 Pollux Drive Edwards AFB CA 93524-7048 Tel: (805) 275-5582, Fax 5852 mcdougallf@lablink.ple.af.mil
72	Cost Analysis	Dietrich E. Koelle MBB Space and Communications and Propulsion Systems Divisi PO Box 801169, D-8000 Munich 80 Germany LtCol Marc Hallada Air Force Research Laboratory (formerly Phillips Laboratory) - PL/LID Tel: (505) 846-4031 HalladaM@plk.af.mil	Francis G. McDougall OLAC PL/RKBA 5 Pollux Drive Edwards AFB CA 93524-7048 Tel: (805) 275-5582, Fax 5852 mcdougallf@lablink.ple.af.mil
73	Trajectory Analysis	Dick Powell Space Systems Division, NASA Langley Research Center Tel: (804) 864-4506	Francis G. McDougall OLAC PL/RKBA 5 Pollux Drive Edwards AFB CA 93524-7048 Tel: (805) 275-5582, Fax 5852 mcdougallf@lablink.ple.af.mil
74	Maui Image Processing	Major Dimmel Air Force Research Laboratory (formerly Phillips Laboratory) - PL/LIMM Tel: (808) 874-1540	LtCol Marc Hallada Air Force Research Laboratory (formerly Phillips Laboratory) - PL/LID Tel: (505) 846-4031 HalladaM@plk.af.mil
75	Chemical Oxygen-Iodine Laser Modeling	Dr. Truesdell Air Force Research Laboratory (formerly Phillips Laboratory) - PL/LIDB Tel: (505) 846-0718	LtCol Marc Hallada Air Force Research Laboratory (formerly Phillips Laboratory) - PL/LID Tel: (505) 846-4031 HalladaM@plk.af.mil
76	Laser Propogation	Lt Col O'Keefe Air Force Research Laboratory (formerly Phillips Laboratory) - PL/LIAE Tel: (505) 846-4016	LtCol Marc Hallada Air Force Research Laboratory (formerly Phillips Laboratory) - PL/LID Tel: (505) 846-4031 HalladaM@plk.af.mil
77	Airborne Laser Design	Capt Ching Air Force Research Laboratory (formerly Phillips Laboratory) -PL/LIAF Tel: (505) 846-5049	LtCol Marc Hallada Air Force Research Laboratory (formerly Phillips Laboratory) - PL/LID Tel: (505) 846-4031 HalladaM@plk.af.mil

ET/Project	Title	Major Players	Other Players
78	Semiconductor Laser Analysis	Mr Pchelkin Air Force Research Laboratory (formerly Phillips Laboratory) - PL/LIDA Tel: (505) 846-4758	LtCol Marc Hallada Air Force Research Laboratory (formerly Armstrong Laboratory) - PL/LID Tel: (505) 846-4031 HalladaM@plk.af.mil
79	Passive Scalar Models	Dr DeHainaut Air Force Research Laboratory (formerly Armstrong Laboratory) – PL/LIMS Tel: (505) 846-3262	LtCol Marc Hallada PL/LID (505) 846-4031 HalladaM@plk.af.mil
80	Integration of Multidimensional Models	Dr Clayton Air Force Research Laboratory (formerly Armstrong Laboratory) - PL/LIDN Tel: (505) 846-4750	LtCol Marc Hallada PL/LID (505) 846-4031 HalladaM@plk.af.mil
81	Hyperspectral Image Modeling	Mr Czyzak Air Force Research Laboratory (formerly Phillips Laboratory) - PL/LIMI Tel: (505) 846-4844	LtCol Marc Hallada PL/LID (505) 846-4031 HalladaM@plk.af.mil
82	Adaptive Optics Simulation	Major Leatherman Air Force Research Laboratory (formerly Armstrong Laboratory) - PL/LIGR Tel: (505) 846-8923	LtCol Marc Hallada PL/LID (505) 846-4031 HalladaM@plk.af.mil
83	Computer-Generated Forces	Lt Col Martin Stytz and Dr. Eugene Santos, Jr. Air Force Institute of Technology Tel: (513) 255-9270 mstytz@afit.af.mil , esantos@afit.af.mil Dr John Laird Associate Professor, University of Michigan Tel: (313) 747-1761 Laird@umich.edu	Capt Mark Edwards Phillips Laboratory. Geophysics Directorate (617) 377-4008 medwards@plh.af.mil
84	Joint Modeling and Simulation System (J-MASS)	William K. McQuay Air Force Research Laboratory (formerly Armstrong Laboratory) - WL/AASE Bldg 620 2241 Avionics Cir, Rm N3-F22 Wright-Patterson AFB OH 45433 Tel: (513) 255-4511 mcquaywk@aa.wpafb.af.mil Dr Jerry Arnett ASC/XRJ Wright-Patterson AFB OH 45433	

ET/ Project	Title	Major Players	Other Players
85	Desktop M&S	William K. McQuay Air Force Research Laboratory (formerly Wright Laboratory) WL/AASE Bldg 620, 2241 Avionics Cir, Rm N3-F22 Wright-Patterson AFB, OH 45433 Tel: (513) 255-4511 Mcquaywk@aa.wpafb.af.mil SAIC, EC M&S Division 1321 Research Park Drive Beavercreek OH 45432 Spectra Research Inc. 7071 Corporate Way, Suite 108 Dayton OH 45459	
86	Collaborative Virtual Prototyping	William K. McQuay Air Force Research Laboratory (formerly Wright Laboratory) WL/AASE Bldg 620, 2241 Avionics Cir, Rm N3-F22 Wright-Patterson AFB, OH 45433 Tel: (513) 255-4511 Mcquaywk@aa.wpafb.af.mil Gary Jones Simulation Based Design, DARPA/ITO Michael K. Murray & George Vogel Air Force Research Laboratory (formerly Wright Laboratory) WL/AAJW Wright-Patterson AFB OH 45433 Tel: (513) 255-4174 Murraymk@aa.wpafb.af.mil Brian Clayton & Jerry Dague SAIC, 101 Woodman Drive, Suite 103 Dayton OH 45431 Daniel P. Schiavone, Vance Saunders, Larry Jobson, & Mark Speed Ball Aerospace and Technologies Corp. 2875 Presidential Dr, Ste 180 Fairborn, Ohio 45324 Tel: (513) 320-4060 Fax: (513) 429-1687 Dschiavone@ball.com	

ET/ Project	Title	Major Players	Other Players
87	Khoros -The Visual Programming Environment	Khoral Research Inc. (KRI) 6001 Indian School Rd. NE, Suite 200 Albuquerque NM 87110 Tel: (505) 837-6500 Fax: (505) 881-3842 khoros-request@khoros.unm.edu DARPA/ISO Dr Mark Davis 3701 N. Fairfax Dr. Arlington VA 22208-1714 Sverdrup Technology Inc. Donnie Cates 4200 Colonel Glenn Hwy, Suite 500 Beavercreek OH 45431 Tel: (513) 429-5056	Jacqueline Toussaint Air Force Research Laboratory (formerly Wright Laboratory) AAMR 2241 Avionics Circle RM.N3-Y6 Wright-Patterson AFB OH 45433-7333
88	Resolution and Validation Manager	Daniel P. Schiavone, John Prikkel, James Hooker Ball Aerospace and Technologies Corp. 2875 Presidential Dr, Suite 180 Fairborn OH 45324 Tel: (513) 320-4060 Fax: (513) 429-1687 Dschiavone@ball.com Ronald Clericus QuesTech Inc. 5717 Huberville Ave Dayton OH 45431 Tel: (513) 476-7248 Marilyn Shaw Air Force Research Laboratory (formerly Wright Laboratory) WL/AASE-2 Wright-Patterson AFB OH 45433 Tel: (513) 255-4264	William K. McQuay Air Force Research Laboratory (formerly Wright Laboratory) - WL/AASE Bldg 620, 2241 Avionics Cir, Rm N3-F22 Wright-Patterson AFB, OH 45433 Tel: (513) 255-4511 Mcquaywk@aa.wpafb.af.mil
89	Exercise Management	Larry Jobson, Daniel P. Schiavone, Mark Speed, Vance Saunders Ball Aerospace and Technologies Corp. 2875 Presidential Dr, Ste 180 Fairborn OH 45324 Tel: (513) 320-4060 Fax: (513) 429-1687 Dschiavone@ball.com	Capt Mike Lightner Air Force Research Laboratory (formerly Wright Laboratory) AASE Bldg 620, 2241 Avionics Cir, Rm N3-F22 Wright-Patterson AFB OH 45433 Tel: (513) 255-4511 lightngm@aa.wpafb.af.mil

ET/ Project	Title	Major Players	Other Players
90	J-MASS Extensions For DoD HLA Interoperability	Capt Mike Lightner Air Force Research Laboratory (formerly Wright Laboratory) WL/AASE Bldg 620, 2241 Avionics Cir, Rm N3-F22 Wright-Patterson AFB OH 45433 Tel: (513) 255-4511 Lightngm@aa.wpafb.af.mil SAIC EC M&S Division 1321 Research Park Drive Beavercreek OH 45432	
91	Automated J-MASS Tools for DoD HLA-Compliant Simulation Development	Capt Mike Lightner Air Force Research Laboratory (formerly Wright Laboratory) - WL/AASE Bldg 620, 2241 Avionics Cir, Rm N3-F22 Wright-Patterson AFB OH 45433 Tel: (513) 255-4511 Lightngm@aa.wpafb.af.mil SAIC EC M&S Division 1321 Research Park Drive Beavercreek OH 45432	
92	IRCM Modeling	Michael K. Murray Air Force Research Laboratory (formerly Wright Laboratory) - WL/AAJW Wright-Patterson AFB OH 45433 Tel: (513) 255-4174 murraymk@aa.wpafb.af.mil Dr George Vogel, Ed Huber, Brian Clayton, Dave Miller, and others that work in the DIME Lab , Avionics Directorate, Air Force Research Laboratory (formerly Wright Laboratory).	
93	Modeling the Variability of IR Threat Systems	Michael K. Murray Air Force Research Laboratory (formerly Wright Laboratory) - WL/AAJW Wright-Patterson AFB OH 45433 murraymk@aa.wpafb.af.mil Dr George Vogel, Ed Huber, Dave Miller, Brian Clayton, and others	

ET/ Project	Title	Major Players	Other Players
94	Advanced Modeling Methods	Brian L. Clayton SAIC 101 Woodman Drive Suite 103 Dayton OH 45431 Bclayton@erinet.com Jerry Dague SAIC 101 Woodman Drive Suite 103 Dayton OH 45431 George Vogel Air Force Research Laboratory (formerly Wright Laboratory) - WL/AAJW Wright-Patterson AFB,OH 45433 Tel: (513) 255-7102	
95	Thermal Simulations using the COYOTE Computer Code	Roy Hogan, David Gartling, Mike Glass, Dave Kuntz, and Randy Lober Thermal Sciences Department Sandia National Laboratories P.O. Box 5800, MS-0835 Albuquerque NM 87185-0835 Other computer codes for simulating thermal problems are PATRAN/P-THERMAL, SINDA, and codes from various software vendors.	
96	Fire Modeling and Simulation	Sandia National Laboratories Fire Science and Technology Team SINTEF Applied Thermodynamics (Trondheim, Norway)	Sandia National Laboratories Jaime Moya, MS 0865, Org. 9735 P.O. Box 5800 Albuquerque NM 87185-0865 Tel: (505) 844-7955 Fax: (505) 844-7858 JLMOYA@sandia.gov
97	MUSE - Multidimensional User-oriented Synthetic Environment	Dr Creve Maples MuSE Technologies, Inc. 1601 Randolph Rd SE, Ste 210 Albuquerque NM 87106 Tel: (505) 843-6873 Fax: (505) 766-9123 info@musetech.com	

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98	Hearing Functional Evaluation	Lt Col. Allen Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/AOC Brooks AFB TX 78235-5000 Tel: DSN 240-2177 **CMI is currently investigating this area as part of the Small Business Innovative Research Program:** Elaine Mendoza, President and CEO Jun Zhou, Ph.D., Senior Research Engineer Conceptual MindWorks, Inc. (CMI) 4318 Woodcock Drive, Suite 210 San Antonio TX 78228-1316 Tel: (210) 737-0777 emendoza@mail.teamcmi.com jun@mail.teamcmi.com Other players include Virtual Corporation and possibly the entertainment industry.	
99	Cognitive Modeling	John R. Anderson, Wes Regian, and Val Shute are well known in cognitive modeling. David Rummelhart, Hecht Nielssen, Steve Grossberg, Karen Carpenter are all known internationally for neural networks Some or all of these scientists perform research in the cognitive domain. AFOSR is a leading Air Force Focal Point for research in this area, DSN 240-8075.	
100	Portable Neurological Function Automated Diagnostic Device	Dr Grant McMillan Air Force Research Laboratory (formerly Armstrong Laboratory) - AL/CF Human Systems Center Wright-Patterson AFB OH 45433 DSN 785-3602	

ET/ Project	Title	Major Players	Other Players
101	Multi-Level and Cross Resolution Modeling	DMSO Dick Hillestad and Paul Davis at RAND Tel: (310) 393-0411 Paul_Davis@rand.org Ben Wise at SAIC Paul Reynolds	
102	Exploratory Modeling	Steve Bankes RAND Tel: (310) 393-0411, Steven_Bankes@rand.org	
103	Designing Virtual/Live/Constructive Simulation Experiments	Will Brooks US Army Materiel Systems Analysis Activity Aberdeen Proving Ground MD 21005-5071 wbrooks@arl.mil LtCol Dennis Lester Det 4 505 CCEG 1655 First St, SE Kirtland AFB NM 87117-5617 LESTER@awcnet.eglin.af.mil Dr Tom Lucas RAND 1700 main Street Santa Monica CA 90407-2138 Tom_Lucas@rand.org Bryson McCool US Army TRAC-WSMR White Sands Missile Range, NM 88002-5502	

ET/ Project	Title	Major Players	Other Players
104	Generalized Networks Algorithms (for object movement and object interactions	Richard Hillestad RAND Tel: (310) 393-0411 Richard_Hillestad@rand.org Louis Moore RAND Tel: (310) 393-0411 Louis_Moore@rand.org Wayne Zandberg S3I Tel: (703) 684-8268 s3l@interramp.com	
105	Air Campaign Optimization	Dick Hillestad RAND Leon Goodson	
106	Genetic Algorithms	Gary Liberson RAND Tel: (310) 393-0411 x6807 Gary_Liberson@rand.org Bruce Dyke McDonnell Douglas Tel: (314) 232-3657	
107	Human Representation Models for Semi-Automated Forces	Mr Neal Takamoto Systems Analyst Systems Research Laboratories, Inc. Terry A. Benline Systems Research Laboratories P.O. Box 35482 Brooks AFB TX 78235 tbenline@alcft.brooks.af.mil	
108	Vestibular System Modeling	Aerospace Medicine Directorate Air Force Research Laboratory (formerly Armstrong Laboratory) Human Systems Center Brooks AFB TX 78235-5000 Lt. Col. Allen, AL/AOC Tel: DSN 240-2177	

ET/ Project	Title	Major Players	Other Players
109	Expert System Application to Computational Fluid Dynamics (CFD) Simulation Process	Dr Ashok K. Singhal CFD Research Corp. 3325 Triana Blvd Huntsville AL 35805 Tel: (205) 536-6576 Dr Laura C. Rodman Nielsen Engineering & Research Inc 526 Clyde Ave Mountainview CA 94043 Tel: (415) 968-9457 ext 233 Dr Leonard P. Wesley Intellex 366 Masthead Ln Foster City CA 94494 Tel: (415) 572-1646	Gregory O. Stecklein Air Force Research Laboratory (formerly Wright Laboratory) - WL/FIMC Bldg 450, 2645 Fifth St, Suite 7 Wright-Patterspm AFB OH 45433-7913 Tel: (513) 255-3761 teck@fim.wpafb.af.mil
110	Simulation of Lubricated Contacts and Dynamics of Rolling Element Bearings	Society of Tribologists and Lubrication Engineers American Society of Mechanical Engineers Shashi K. Sharma Air Force Research Laboratory (formerly Wright Laboratory) - WL/MLBT Bldg 654, 2941 P St, Suite 1 Wright-Patterson AFB OH 45433-7750 Tel: (513) 255-9029 Sharmask@ml.wpafb.af.mil Nelson Forster Air Force Research Laboratory (formerly Wright Laboratory) - WL/POSL	
111	Epitaxial Growth Modeling	Dr Dmitri Vedensky Dept of Physics The Blackett Laboratory Imperial College London SW& 2BZ United Kingdom	Dr Donald L. Dorsey Air Force Research Laboratory (formerly Wright Laboratory) - WL/MLPO Bldg 651, 3005 P St, Suite 6 Wright-Patterson AFB OH 45433-7707 Tel: (513) 255-4474 ext. 3236 dorseydl@ml.wpafb.af.mil
112	Atomic-Level Modeling and Simulation of Materials	Dr William A. Goddard Caltech, 139-74 Pasadena CA 91125 Tel: (818) 395-2731 debi@wag.caltech.edu	Dr Ruth Pachter Air Force Research Laboratory (formerly Wright Laboratory) – WL/MLPJ 3005 P St, Suite 1 Wright-Patterson AFB OH 45433-7702 Tel: (513) 255-6671 ext. 3158 pachterr@ml.wpafb.af.mil

ET/ Project	Title	Major Players	Other Players
113	Quantum Mechanical Calculations and Molecular Dynamics Simulaitons for Obtaining Non-Structural Material Properties	Dr Francois Baronnet University of Nancy France SUBSTHAL group in Europe Harvey L. Paige Air Force Research Laboratory (formerly Wright Laboratory) - WL/MLBT Bldg 654 2941 P St, Suite 1 Wright-Patterson AFB OH 45433-7750 Tel: (513) 255-9038 Paigehl@ml.wpafb.af.mil	
114	Modeling of Composite Bolted Joints	F.K. Chang Stanford University J. Eisenmann Lockheed Martin Sawicki and P. Grant Boeing Helicopter J. Hart Smith McDonnell Douglas F.L. Mathews Centre for Composite Materials ICST, UK C. Poog Institute for Aerospace Research Canada J. Baure DASA Germany	Capt Jeffery R. Schaff Air Force Research Laboratory (formerly Wright Laboratory) - WL/MLBM Bldg 654 2941 P St, Suite 1 Wright-Patterson AFB OH 45433-7750 Tel: (513) 255-3580
115	Modeling, Simulation, and Analysis (MS&A) Support to Aerospace Research and Acquisition	US Army Academia Study houses Of interest to DMSO, USAF/XOM, and others	Steve Wourms ASC/XRA, Bldg 11A 1970 3rd St, Suite 2 Wright-Patterson AFB OH 45433-7209 wourssj@xr.wpafb.af.mil

ET/Project	Title	Major Players	Other Players
116	Virtual Manufacturing	James W. Poindexter Air Force Research Laboratory (formerly Wright Laboratory) - WL/MTIM 2977 P St, Suite 6 Wright-Patterson AFB OH 45433-7739 Tel: (513) 255-8589 poindejw@ml.wpafb.af.mil Michael F. Hitchcock Air Force Research Laboratory (formerly Wright Laboratory) - WL/MTIM 2977 P St, Suite 6 Wright-Patterson AFB OH 45433-7739 Tel: (513) 255-7371 Hitchcmf@ml.wpafb.af.mil Ram Sriram Lockheed Martin Missiles and Space O/96-20, Bldg. 254F 3251 Hanover Street Palo Alto CA 94304 Tel: (415) 354-5203 sriram_r@mm.rdd.lmsc.lockheed.com Rendell R. Hughes Lockheed Martin Aeronautical Systems 86 Cobb Drive Marietta GA 30063-0685 Tel: (770) 494-9441 rhughes@neterve.lasc.lockheed.com Edward Lin Room 0111, ERB (093) Institute for Systems Research College Park MD 20742 Tel: (301) 405-6571	

ET/Project	Title	Major Players	Other Players
117	Nonlinear Indicial Response Modeling	Dr Patrick H. Reisenthel Chief Scientist Nielsen Engineering and Research Inc. 526 Clyde Avenue Tel: (415) 968-9457 ext. 225 phr@nearinc.com Jerry E. Jenkins (and associates) Air Force Research Laboratory (formerly Wright Laboratory) - WL/FIGC Bldg 146, 2210 Eighth Street, Suite 11 Wright-Patterson AFB OH 45433-7521 Tel: (513) 255-8485 jerry@figc.flight.wpafb.af.mil	Capt Deborah S. Grismer Air Force Research Laboratory (formerly Wright Laboratory) - WL/FIGC Bldg 146 2210 Eighty St, Suite 11 Wright-Patterson AFB OH 45433-7521 Tel: (513) 255-8494 grismeds@b045mail.wpafb.af.mil
118	Flying Qualities of Manned Aircraft - Simulator Effectiveness and Required Techniques for Pilot-Induced Oscillation (PIO) Studies	Air Force Research Laboratory (formerly Wright Laboratory) Flight Control Division (WL/FIG) Boeing Aircraft Company Douglas Aircraft Company Lockheed Aircraft Company	Wayne Thor Air Force Research Laboratory (formerly Wright Laboratory) - WL/FIGC Bldg 146 2210 Eighth St, Ste 21 Wright-Patterson AFB OH 45433-7531 Tel: (513) 255-8497 Thorwa@wl.wpafb.af.mil
119	Real-Time Piloted Engineering Flight Simulation	Lockheed McDonnell Douglas Northrop Grumman Boeing U.S. Navy at Patuxent River MD	Don R. Gum Tel: (513) 255-4690 gumdr@wl.wpafb.af.mil
120	Subsystems Integrated Design Assessment Technology/Integrated Subsystems Interactions Tradeoff Evaluation (SIDAT/INSITE)	Lockheed Martin Aerospace Company (SIDAT Prime) McDonnell Douglas Boeing Northrop Sundstrand Air Force Research Laboratory (formerly Wright Laboratory) - WL/POPS Texas Instruments Allied Signal Georgia Tech SAIC	Donald J. Reese, Jr. Tel: (513) 255-3021 Reesedj@b045mail.flight.wpafb.af.mil

ET/ Project	Title	Major Players	Other Players
121	Computational Fluid Dynamics (CFD) and Combustion	Dr W. Melvyn Roquemore Air Force Researach Laboratory (formerly Wright Laboratory) - WL/POSC Bldg 490 1790 Loop Road North Wright-Patterson AFB OH 45433-7103 melr@ward.appl.wpafb.af.mil Dr R. Ni Pratt and Whitney Tel: (860) 565-1383 Dr A. Singhal CFD Research Corporation Tel: (202) 536-6576 Dr V. Katta Innovative Scientific Solutions Inc. Tel: (513) 255-8781 Dr R. Stubbs NASA Lewis Research Center Tel: (216) 433-2452 Dr H. Mongia General Electric Aircraft Engines Tel: (513) 423-2552 Dr M. Razdan Allison Tel: (317) 230-6404	
122	Rolling Bearing Dynamics Simulation	Dr Pradeep K. Gupta PKG, Inc. 117 Southbury Rd Clifton Park NY 12065-7714 Crawford Meeks AVCON 5210 Lewis Rd Agoura Hills CA 91301-2662	Garry D. Givan Air Force Research Laboratory (formerly Wright Laboratory) - WL/POSL 1790 Loop Rd N Wright-Patterson AFB OH 45433-7103 Tel: (513) 255-1286 givangad@wl.wpafb.af.mil

ET/ Project	Title	Major Players	Other Players
123	Conceptional Technology Integration	Dennis L. Carter, P.E. Air Force Research Laboratory (formerly Wright Laboratory) - WL/FIIB Bldg 45, 2130 Eighth Street Suite 1 Wright-Patterson AFB OH 45433-7543 Tel: DSN 785-4294 carterdl@b045mail.wpafb.af.mil Paul Gelhausen NASA/Ames Research Center Mail Stop 237-11 Moffett Field CA 94035 Tel: (415) 604-5701 Dr Dimitri Mavris School of Aerospace Engineering Georgia Institute of Technology Atlanta GA 30333-0150 Tel: (404) 894-3343 dimitri.marvis@aerospace.gatech.edu Linda K. Poole Lockheed Martin Tactical Aircraft Systems Post Office Box 748, Mail Zone 2655 Fort Worth TX 76101 Tel: (817) 763-2096 Frank Neumann Boeing Defense & Space Group P.O. Box 3707, #MS 4C-70 Seattle, WA 98124-2207 (206) 662-0083 neufdx00@ccmail.ca.boeing.com James E. Cupstid McDonnell Douglas Aerospace Advanced Systems & Technology-Phantom Works Mailcode 106 7126 P.O. Box 516 St Louis MO 63166-0516 Tel: (314) 232-4941 jcupstid@swsmtp01.mdc.com	

ET/ Project	Title	Major Players	Other Players
124	Modeling of Visual Discrimination With and Without Impairments	Lt. Col. McLin Air Force Research Laboratory (formerly Armstrong Laboratory) - AL\OEO Human Systems Center Brooks AFB TX 78235-5000 Tel: DSN 240-3625 Dr Harry Zwick US Army Medical Research Detachment Brooks AFB TX 78235-5000 Tel: DSN 240-4620 Prof Wilson Geisler University of Texas at Austin (has AFOSR grants to develop vision models) The OPR is: AFOSR/NL Bolling AFB DC Tel: DSN 297-4278. Jan Walraven in Holland has worked on making signs and displays better for colorblind people - he is quite famous and some of his work would be applicable. Andrew Watson at NASA Ames is another famous vision modeler.	
125	Decision Logic Design	Dr Robert Kerchner RAND Tel: (202) 296-5000 x 5324 Kerchner@rand.org Mr James Heusmann DMSO (SAIC) Tel: (703) 824-3413 Heusmann@msis.dmso.mil Dr Stephen Downes-Martin Tel: (413) 582-0183 70673.3172@compuserve.com	

ET/ Project	Title	Major Players	Other Players
126	Human Performance Modeling	Dr Robert Kerchner RAND Tel: (202) 296-5000 x 5324 Kerchner@rand.org Dr Herbert H. Bell Air Force Research Laboratory (formerly Armstrong Lab) Warfighter Training Research Division 6001 S. Power Road, Bldg 558 Mesa AZ 85206-0904 Tel: (602) 988-6561 DSN: 474-6561 bell@alhra.af.mil	
127	Data Warehousing	Iris Kameny or Bart Bennett RAND Tel: (310) 393-0411 Iris_Kameny@rand.org Bart_Bennett@rand.org	
128	High Resolution Microlaser-Based, Helmet-Mounted Display	Mr Bob Bergstedt Laser Power Corp. 12777 High Bluff Drive San Diego CA 92130 Tel: (619) 755-0700 Mr Phil Peppler Air Force Research Laboratory (formerly Armstrong Lab) Warfighter Training Research Division 6001 South Power Road, Bldg 558 Mesa AZ 85206-0904 Tel: (602) 988-6561 DSN: 474-6561 Peppler@alhra.af.mil	
129	Microlaser-Based Projection Display for Simulation	Mr Bob Bergstedt Laser Power Corp. 12777 High Bluff Drive San Diego CA 92130 Tel: (619) 755-0700 Mr Phil Peppler Air Force Research Laboratory (formerly Armstrong Lab) Warfighter Training Research Division 6001 South Power Road, Bldg 558 Mesa AZ 85206-0904 Tel: (602) 988-6561 DSN: 474-6561 Peppler@alhra.af.mil	

ET/ Project	Title	Major Players	Other Players
130	A True Three-Dimensional Monitor for Aerospace Applications	Mr Paul Higley Specialty Devices Inc. 1104 Summit Avenue #104 Plano TX 75074 Tel: (214) 578-7501 Mr Phil Peppler Air Force Research Laboratory (formerly Armstrong Lab) 6001 South Power Road, Bldg 558 Mesa AZ 85206-0904 Tel: (602)988-6561 DSN: 474-6561 Peppler@alhra.af.mil	
131	PC-based Generator for Flight Simulation	Mr Brian Spaulding MaK Technologies 185 Alewife Brook Parkway Cambridge MA 01238 Tel: (617) 876-8085 Mr Phil Peppler Air Force Research Laboratory (formerly Armstrong Lab) 6001 South Power Road, Bldg 558 Mesa AZ 85206-0904 Tel: (602) 988-6561 DSN: 474-6561 peppler@alhra.af.mil	

APPENDIX C

AD HOC TEAM'S RATINGS SPREADSHEET

The ratings spreadsheet is organized according to the sequence of Enabling Technology categories and subcategories shown in the M&S Taxonomy in Section 2.0 of this report.

Note: Those survey responses which are M&S projects that use enabling technologies vice those which are "pure" enabling technologies, have an asterisk next to their number in the spreadsheet.

Pertinent Category	No.	Responses: Title	Of potential use in Campaig Level Models (Y/N)	Importance Mear (1-5)	Importance Standard Deviatio	Maturity Mear (1-5)	Maturity Standard Deviatio	Potential for Development Mea (1-5)	Development Potential Standar Deviatio	Science/Application Continuu Mea (1-5)	Science/Application Continuu Standard Deviatio	Activity Mear (1-3)	Uniqueness Mear 1-3)	Composite Score (Sum of al factor rating scales	Subcategory Average Composit Scor	Subcategory Composite Scor Std Deviatio
2.1.1		**M&S Architecture**														
2.1.1	3	Dynamic Structure Modeling and Simulation	Y	2.9	0.83	4.0	0.76	3.5	0.76	3.6	0.52	2	1	17.0		
2.1.1	12	Attributes Extrapolation under High Level Architecture (HLA)	Y	3.7	0.49	3.5	1.22	4.0	0.58	2.1	0.90	2	2	17.4		
2.1.1	15	Unified Framework for design and Implementation of Discrete Event Systems	Y	2.9	0.90	3.4	1.72	2.6	1.40	4.0	0.58	2	1	15.9		
2.1.1	17	Significant Event Detection (SigEvD) in Discrete-Event Simulation	Y	3.0	0.93	4.3	0.89	3.6	0.92	3.8	0.46	3	1	18.6		
2.1.1	20	Graphical Description of Discrete Event Models Behavior	Y	2.4	0.79	4.1	0.38	2.6	1.13	2.4	0.79	3	1	15.6		
2.1.1	22	Advanced M&S Environments for Intelligent and Cognitive Systems	Y	3.0	1.10	4.3	0.52	3.2	0.41	4.0	1.10	2	1	17.5		
2.1.1	25	Fuzzy Discrete Event Systems M&S	Y	2.5	0.55	3.2	1.72	2.8	0.41	3.3	1.21	3	1	15.8		
2.1.1	33	Concurrent Simulation	Y	3.3	0.49	3.3	0.76	3.1	0.38	2.9	0.38	1	1	14.6		
2.1.1	70*	Space Simulation Framework	N	3.3	0.95	2.6	0.98	3.0	1.15	1.9	1.21	2	3	15.7		
2.1.1	84*	Joint Modeling and Simulation System (J-MASS)	Y	3.6	0.74	3.0	1.20	4.1	1.36	2.3	1.04	1	3	17.0		
2.1.1	87*	Khoros -The Visual Programming Environment	N	3.4	0.92	2.0	0.93	2.9	0.99	3.1	1.25	2	1	14.4		
2.1.1	90*	J-MASS Extensions For DoD HLA Interoperability	Y	4.1	1.25	3.6	0.52	3.1	0.64	2.1	0.64	1	3	17.0		
2.1.1	91*	Automated J-MASS Tools for DoD HLA Compliant Simulation Development	Y	3.5	0.76	3.9	1.25	3.5	0.76	2.3	0.89	1	2	16.1		
2.1.1	115*	Modeling, Simulation, and Analysis (MS&A) Support to Aerospace Research and Acquisition	Y	4.1	0.99	3.3	1.16	3.8	1.39	1.8	1.39	1	3	16.9		
2.1.2		**Distributed Communication Technology**														
2.1.2	2	Distributed Simulation Performance Modeling	Y	2.5	0.55	3.3	1.37	2.7	0.52	1.7	1.51	3	1	14.2		
2.1.2	9	Web-Based Simulation	Y	2.5	0.53	4.0	0.93	3.0	0.76	2.9	0.99	3	1	16.4		
2.1.2	11	Small Team Situational Training and Mission Planning/Rehearsal	Y	3.0	1.15	3.9	1.21	3.4	0.53	2.1	0.90	2	1	15.4		
2.1.2	13	Distributed Simulation of Heterogeneous Models	Y	2.6	1.27	4.9	0.38	2.6	1.27	3.7	0.76	3	1	17.7		
2.1.2	71	Network-Based Distributed Computing Systems	Y	2.1	0.38	2.0	0.58	3.1	0.90	2.3	0.95	2	1	12.6		
2.1.2	84*	Joint Modeling and Simulation System (J-MASS)	Y	3.6	0.74	3.0	1.20	4.1	1.36	2.3	1.04	1	3	17.0		
2.1.2	87*	Khoros -The Visual Programming Environment	N	3.4	0.92	2.0	0.93	2.9	0.99	3.1	1.25	2	1	14.4		
2.1.2	90*	J-MASS Extensions For DoD HLA Interoperability	Y	4.1	1.25	3.6	0.52	3.1	0.64	2.1	0.64	1	3	17.0		
2.1.2	91*	Automated J-MASS Tools for DoD HLA Compliant Simulation Development	Y	3.5	0.76	3.9	1.25	3.5	0.76	2.3	0.89	1	2	16.1		
2.1.2	104	Generalized Networks Algorithms	Y	2.7	1.11	3.4	1.27	3.4	0.79	2.0	1.41	2	1	14.6	15.5	1.6
2.2.1.1		**Model Management Tools**														
2.2.1.1	10	Variable Resolution Modeling, Mixed Fidelity Simulation	Y	3.9	0.83	3.8	0.46	3.8	0.89	3.1	0.99	3	1	18.5		
2.2.1.1	14	Database Support for Simulation Model	Y	2.9	0.69	3.6	0.79	2.6	1.27	3.7	0.76	2	1	15.7		
2.2.1.1	15	Unified Framework for Design and Implementation of Discrete Event Systems	Y	2.9	0.90	3.4	1.72	2.6	1.40	4.0	0.58	2	1	15.9		
2.2.1.1	16	Simulation Query Language for Knowledge-Based Systems	Y	2.7	0.82	4.3	1.21	3.2	0.75	4.3	0.82	3	1	18.5		
2.2.1.1	46*	Exercise Management for Distributed Simulations	Y	3.0	0.00	2.1	0.90	3.3	1.11	2.0	1.00	2	1	13.4		
2.2.1.1	51	Software Reuse via Composition	Y	2.9	0.35	3.5	0.93	3.5	0.76	3.1	0.35	2	1	16.0		
2.2.1.1	68*	Decision Support System for Compliance	N	2.2	0.75	2.0	0.89	2.3	1.21	2.0	1.10	2	1	11.5		
2.2.1.1	127	Data Warehousing	N	2.5	0.71	2.5	0.71	3.5	0.71	2.5	0.71	2	1	14.0		
2.2.1.1	43*	Calendaring via the World Wide Web (WWW)	N	1.7	0.76	2.4	1.51	2.6	1.13	2.0	1.00	2	1	11.7		
2.2.1.1	44*	Document Collaboration via the World Wide Web (WWW)	N	2.0	0.82	1.8	0.96	1.8	0.96	2.3	1.26	2	1	10.8		
2.2.1.1	84*	Joint Modeling and Simulation System (J-MASS)	Y	3.6	0.74	3.0	1.20	4.1	1.36	2.3	1.04	1	3	17.0		
2.2.1.1	85*	Desktop M&S	Y	3.6	0.92	2.8	0.46	4.4	0.92	3.1	1.25	1	1	15.9	14.9	2.6
2.2.1.2		**Resolution and Validation Mgt Tools**														
2.2.1.2	10	Variable Resolution Modeling, Mixed Fidelity Simulation	Y	3.9	0.83	3.8	0.46	3.8	0.89	3.1	0.99	3	1	18.5		
2.2.1.2	3	Dynamic Structure Modeling and Simulation	Y	2.9	0.83	4.0	0.76	3.5	0.76	3.6	0.52	2	1	17.0		
2.2.1.2	5	Real-time, Man-in-the-loop Weapon System Simulation	Y	2.7	0.76	2.9	0.90	3.7	0.49	2.3	1.25	2	2	15.6		
2.2.1.2	6	Stochastic Layered Modeling	Y	3.1	0.83	3.1	0.99	3.5	0.93	2.3	0.71	2	1	15.0		
2.2.1.2	7	Model Abstraction	Y	3.5	0.76	4.1	0.90	4.3	0.71	2.6	0.52	3	1	18.5		
2.2.1.2	17	Significant Event Detection (SigEvD) in Discrete-Event Simulation	Y	3.0	0.93	4.3	0.89	3.6	0.92	3.8	0.46	3	1	18.6		
2.2.1.2	21	Hierarchical Simulation and Statistical Fidelity	Y	3.3	0.71	4.3	0.89	3.5	1.07	3.0	1.20	3	1	18.0		
2.2.1.2	47	Agent-based Simulations of Complex and Complex Adaptive Systems	N	2.5	0.55	3.2	1.17	2.8	0.41	3.7	0.82	3	1	16.2		
2.2.1.2	49	Representational Resolution and Fidelity	Y	3.5	0.76	3.8	0.89	3.8	0.71	2.9	0.83	2	2	17.9		
2.2.1.2	93	Modeling the Variability of IR Threat Systems	Y	3.0	0.00	3.8	1.39	3.0	0.87	2.1	1.27	3	2	16.9		
2.2.1.2	101	Multi-level and Cross Resolution modeling	Y	3.0	0.58	3.6	0.53	3.1	0.69	2.6	0.79	2	1	15.3		
2.2.1.2	18	Automatic Model Verification	Y	2.6	0.53	3.7	0.95	3.3	0.49	4.6	0.79	3	1	18.1		
2.2.1.2	34	Quantification of Fidelity. Relating simulator fidelity to counterpart operational system usage.	N	2.8	0.75	3.5	0.84	3.5	0.55	2.8	0.75	2	2	16.7		
2.2.1.2	35	Simulated Environment Interoperability Between and Among Mixed Fidelity Simulators	Y	3.4	0.53	3.1	0.90	3.6	0.79	2.1	0.90	2	2	16.3		
2.2.1.2	40	Multi-Resolution Simulation	Y	3.5	0.53	4.1	0.83	3.4	0.92	2.5	0.53	2	1	16.5		
2.2.1.2	42	After Action Review (AAR) and Unit Performance Measurement	Y	3.0	0.89	2.8	1.17	3.3	1.21	2.2	0.98	2	2	15.3		
2.2.1.2	88	Resolution and Validation Manager	Y	3.0	0.00	3.3	0.71	3.6	0.73	2.6	0.73	2	2	16.4	16.9	1.2
2.2.1.3		**Experimental Frame Methodology**														

Pertinent Category	No.	Responses: Title	Of potential use in Campaig Level Models (Y/N)	Importance Mean (1-5)	Importance Standard Deviation	Maturity Mean (1-5)	Maturity Standard Deviation	Potential for Development Mean (1-5)	Development Potential Standar Deviatio	Science/Application Continuu Mea (1-5)	Science/Application Continuu Standard Deviatio	Activity Mean (1-3)	Uniqueness Mean 1-3)	Composite Score (Sum of all factor rating scales	Subcategory Average Composit Scor	Subcategory Composite Scor Std Deviatio
2.2.1.3		**Simulaton Design/Experiment Frame Methods**														
2.2.1.3	1	Run-Time Adaptive Computer Interfaces	Y	2.7	0.82	2.0	1.10	3.0	1.10	1.8	0.75	3	1	13.5		
2.2.1.3	14	Database Support for Simulation Model	Y	2.9	0.69	3.6	0.79	2.6	1.27	3.7	0.76	2	1	15.7		
2.2.1.3	15	Unified framework for design and implementation of discrete event systems	Y	2.9	0.90	3.4	1.72	2.6	1.40	4.0	0.58	2	1	15.9		
2.2.1.3	16	Simulation Query Language for Knowledge-Based Systems	Y	2.7	0.82	4.3	1.21	3.2	0.75	4.3	0.82	3	1	18.5		
2.2.1.3	30	Model Simplification through Formalism Transformation	Y	2.8	0.89	4.1	0.64	3.1	0.35	2.9	0.83	2	1	15.9		
2.2.1.3	102	Exploratory Modeling	Y	2.4	1.52	4.0	0.71	2.4	0.89	3.8	0.84	3	1	16.6		
2.2.1.3	19	Experimental Frame Methodology	Y	2.8	0.46	3.8	1.04	3.4	0.92	3.3	0.71	3	1	17.1		
2.2.1.3	20	Graphical Description of Discrete Event Models Behavior	Y	2.4	0.79	4.1	0.38	2.6	1.13	2.4	0.79	3	1	15.6		
2.2.1.3	60	Simulation Design and Evaluation Using Operator State Monitoring	Y	2.5	0.84	2.8	0.98	3.2	0.75	2.3	1.21	2	2	14.8		
2.2.1.3	102	Exploratory Modeling	Y	2.4	1.52	4.0	0.71	2.4	0.89	3.8	0.84	3	1	16.6		
2.2.1.3	103	Designing Virtual/Live/Constructive Simulation Experiments	Y	3.3	0.95	3.6	0.79	4.0	0.58	2.3	0.76	2	2	17.1		
2.2.1.3	120*	Subsystems Integrated Design Assessment Technology/Integrated Subsystems Interactions Tradeoff Evaluation (SIDAT/INSITE)	N	2.7	1.03	3.3	1.37	2.8	1.17	2.0	0.00	1	2	13.8		
2.2.1.3	80*	Integration of Multidimensional Models	N	3.2	1.47	3.2	0.98	2.5	1.38	3.0	1.26	2	2	15.8		
2.2.1.3	81*	Hyperspectral Image Modeling	N	2.3	0.96	3.8	1.17	2.2	0.98	2.8	1.17	2	2	15.1		
2.2.1.3	83	Computer Generated Forces	Y	3.6	1.06	3.5	1.07	3.4	0.52	1.9	0.99	2	2	16.4		
2.2.1.3	84*	Joint Modeling and Simulation System (J-MASS)	Y	3.6	0.74	3.0	1.20	4.1	1.36	2.3	1.04	1	3	17.0		
2.2.1.3	85*	Desktop M&S	Y	3.6	0.92	2.8	0.46	4.4	0.92	3.1	1.25	1	1	15.9		
2.2.1.3	86*	Collaborative Virtual Prototyping	Y	4.4	0.92	3.1	0.99	4.1	0.99	2.1	0.83	2	1	16.8		
2.2.1.3	87*	Khoros - The Visual Programming Environment	N	3.4	0.92	2.0	0.93	2.9	0.99	3.1	1.25	2	1	14.4		
2.2.1.3	90*	J-MASS Extensions For DoD HLA Interoperability	Y	4.1	1.25	3.6	0.52	3.1	0.64	2.1	0.64	1	3	17.0		
2.2.1.3	91*	Automated J-MASS Tools for DoD HLA Compliant Simulation Development	Y	3.5	0.76	3.9	1.25	3.5	0.76	2.3	0.89	1	2	16.1	16.0	1.2
2.2.1.4		**Data Acquisition and Insertion**														
2.2.1.4	37*	Seamless Universal Voice Interchange System (SUVIS)	Y	3.2	0.41	4.8	0.41	3.3	0.52	3.0	0.63	3	2	19.3		
2.2.1.4	92	IRCM Modeling	N	3.1	0.99	4.6	0.74	2.9	0.35	1.6	1.06	3	2	17.3		
2.2.1.4	97	MUSE (Multi-dimensional User-oriented Synthetic Environment)	Y	3.0	0.71	3.2	1.30	3.6	1.14	2.8	0.84	2	1	15.6		
2.2.1.4	125	Decision Logic Design	N	2.0	0.00	3.0	1.41	3.0	0.00	3.5	0.71	2	2	15.5		
2.2.1.4	14	Database Support for Simulation Model	Y	2.9	0.69	3.6	0.79	2.6	1.27	3.7	0.76	2	1	15.7		
2.2.1.4	16	Simulation Query Language for Knowledge-Based Systems	Y	2.7	0.82	4.3	1.21	3.2	0.75	4.3	0.82	3	1	18.5	17.0	1.7
2.2.2		**Hierarchical Simulation**														
2.2.2	6	Stochastic Layered Modeling	Y	3.1	0.83	3.1	0.99	3.5	0.93	2.3	0.71	2	1	15.0		
2.2.2	7	Model Abstraction	Y	3.5	0.76	4.1	0.90	4.3	0.71	2.6	0.52	3	1	18.5		
2.2.2	10	Variable Resolution Modeling, Mixed Fidelity Simulation	Y	3.9	0.83	3.8	0.46	3.8	0.89	3.1	0.99	3	1	18.5		
2.2.2	17	Significant Event Detection (SigEvD) in Discrete-Event Simulation	Y	3.0	0.93	4.3	0.89	3.6	0.92	3.8	0.46	3	1	18.6		
2.2.2	23	Neural Networks for Metamodeling	Y	2.7	0.49	3.7	1.25	3.3	0.49	3.4	0.79	3	1	17.1		
2.2.2	24	Rational Functions in Metamodeling	Y	2.3	0.50	1.9	1.36	2.0	1.12	2.3	1.58	2	1	11.6		
2.2.2	25	Fuzzy Discrete Event Systems M&S	Y	2.5	0.55	3.2	1.72	2.8	0.41	3.3	1.21	3	1	15.8		
2.2.2	26	Inductive Modeling/Soft Computing	N	1.9	0.69	2.6	1.27	2.3	0.95	3.6	0.79	3	1	14.3		
2.2.2	27	Fuzzy Systems	N	2.5	0.55	1.7	1.21	2.8	1.17	3.0	1.55	2	1	13.0		
2.2.2	28	General Information Theory (GIT)	N	2.2	0.41	4.2	0.75	2.3	0.82	4.2	0.41	3	1	16.8		
2.2.2	29	Fuzzy Modeling	N	2.2	0.41	3.5	1.22	2.7	1.03	3.5	1.05	2	1	14.8		
2.2.2	30	Model Simplification through Formalism Transformation	Y	2.8	0.89	4.1	0.64	3.1	0.35	2.9	0.83	2	1	15.9		
2.2.2	34	Quantification of fidelity. Relating simulator fidelity to counterpart operational system usage	N	2.8	0.75	3.5	0.84	3.5	0.55	2.8	0.75	2	2	16.7		
2.2.2	40	Multi-Resolution Simulation	Y	3.5	0.53	4.1	0.83	3.4	0.92	2.5	0.53	2	1	16.5		
2.2.2	49	Representational Resolution and Fidelity	Y	3.5	0.76	3.8	0.89	3.8	0.71	2.9	0.83	2	2	17.9		
2.2.2	53	Model Abstraction Via Solution of the Inverse Problem to Define a Reduced Order Model	Y	3.4	0.74	3.5	1.20	3.0	0.76	2.6	0.74	3	1	16.5		
2.2.2	54	Intelligent Simulation Objects	Y	3.3	0.76	3.9	1.07	3.4	0.53	3.0	0.00	2	1	16.6		
2.2.2	59	Human Operator Cognitive Modeling for Mixed Level Analysis	Y	3.6	0.55	3.4	0.89	3.2	0.45	2.2	1.10	2	2	16.4		
2.2.2	80*	Integration of Multidimensional Models	N	3.2	1.47	3.2	0.98	2.5	1.38	3.0	1.26	2	2	15.8		
2.2.2	82*	Adaptive Optics Simulation	Y	3.2	1.47	3.5	1.05	2.7	1.37	2.8	0.98	2	2	16.2		
2.2.2	88	Resolution and Validation Manager	Y	3.0	0.00	3.3	0.71	3.6	0.73	2.6	0.73	2	2	16.4		
2.2.2	101	Multi-level and Cross Resolution modeling	Y	3.0	0.58	3.6	0.53	3.1	0.69	2.6	0.79	2	1	15.3	16.1	1.7
2.3.1		**Human Modeling**														
2.3.1	108	Vestibular System Modeling	N	2.6	0.52	4.3	0.71	2.9	0.64	3.9	0.64	3	2	18.6		
2.3.1	124	Modeling of visual discrimination with and without impairments	N	3.0	1.41	3.5	0.71	3.0	0.00	3.5	0.71	2	3	18.0		
2.3.1	99	Cognitive Modeling	Y	2.9	0.90	3.1	0.69	3.3	0.49	3.9	0.38	2	1	15.9		
2.3.1	126	Human Performance Modeling	N	3.5	0.71	3.0	0.00	3.5	0.71	3.0	0.00	2	2	17.0	17.4	1.2
2.3.2		**Environmental Modeling**														
2.3.2	45	Environment representation in Advanced Distributed Simulation entity-level, force-on-force simulations	Y	3.6	0.53	2.7	0.49	3.3	1.11	1.6	0.79	2	2	15.1		
2.3.2	63	Environmental Molecular Modeling (EMM)	N	2.8	0.75	3.2	0.98	3.0	1.55	2.7	1.03	2	2	15.7		
2.3.2	64	Risk Assessment/Dispersion Modeling	N	2.8	1.33	1.5	0.55	2.0	1.55	1.5	0.84	2	2	11.8		
2.3.2	65	Emissions Inventory/Dispersion Modeling	N	2.3	0.52	1.5	0.55	2.2	1.33	1.8	1.17	2	2	11.8		

• APPENDIX C: AD HOC TEAM'S RATINGS SPREADSHEET

Pertinent Category	No.	Responses: Title	Of potential use in Campaig Level Models	Importance Mear	Importance Standard Deviatio	Maturity Mear	Maturity Standard Deviatio	Potential for Development Mear	Development Potential Standar Deviatio	Science/Application Continuu Mea	Science/Application Continuu Standard Deviatio	Activity Mear	Uniqueness Mear	Composite Score (Sum of si factor rating scales	Subcategory Average Composit Scor	Subcategory Composite Scor Std Deviatio
			(Y/N)	(1-5)		(1-5)		(1-5)		(1-5)		(1-3)	1-3)			
2.3.2		**Environmental Modeling**														
2.3.2	45*	Environment representation in Advanced Distributed Simulation entity-level, force-on-force simulations	Y	3.6	0.53	2.7	0.49	3.3	1.11	1.6	0.79	2	2	15.1		
2.3.2	63	Environmental Molecular Modeling (EMM)	N	2.8	0.75	3.2	0.98	3.0	1.55	2.7	1.03	2	2	15.7		
2.3.2	64*	Risk Assessment/Dispersion Modeling	N	2.8	1.33	1.5	0.55	2.0	1.55	1.5	0.84	2	2	11.8		
2.3.2	65*	Emissions Inventory/Dispersion Modeling	N	2.3	0.52	1.5	0.55	2.2	1.33	1.8	1.17	2	2	11.8		
2.3.2	66*	Dispersion Modeling- Higher Order Turbulence Model	N	2.3	0.52	2.7	1.51	2.3	1.21	2.0	1.10	2	2	13.3		
2.3.2	76*	Laser Propogation	Y	2.8	0.41	3.8	1.17	3.0	0.00	3.0	0.89	2	3	17.7	14.2	2.3
2.3.3		**Scientific and Engineering Modeling Methods**														
2.3.3	6	Stochastic Layered Modeling	Y	3.1	0.83	3.1	0.99	3.5	0.93	2.3	0.71	2	1	15.0		
2.3.3	23	Neural Networks for Metamodeling	Y	2.7	0.49	3.7	1.25	3.3	0.49	3.4	0.79	3	1	17.1		
2.3.3	36	Physics-Based Sensor Models	N	2.4	0.53	3.1	0.90	2.9	0.69	2.6	0.98	2	2	15.0		
2.3.3	37*	Seamless Universal Voice Interchange System (SUVIS)	Y	3.2	0.41	4.8	0.41	3.3	0.52	3.0	0.63	3	2	19.3		
2.3.3	38	Computer Generated Forces	Y	3.6	0.98	2.3	0.76	3.1	1.21	2.0	0.58	2	2	15.0		
2.3.3	52	Generative Analysis	Y	3.4	0.74	4.3	0.59	3.8	0.89	3.1	1.25	3	1	18.6		
2.3.3	64*	Risk Assessment/Dispersion Modeling	N	2.8	1.33	1.5	0.55	2.0	1.55	1.5	0.84	2	2	11.8		
2.3.3	67*	Dispersion Modeling - Fuel Jettison Model	N	2.8	1.17	2.3	1.21	2.2	0.98	2.2	0.98	2	2	13.5		
2.3.3	72*	Cost Analysis Tool for Space Transportation Systems	Y	2.7	0.52	1.8	1.17	1.3	0.82	1.5	1.22	2	3	12.3		
2.3.3	73*	Trajectory analysis	Y	2.5	1.05	2.2	1.47	2.3	1.37	1.5	1.22	1	3	12.5		
2.3.3	74*	Maui Image Processing	N	2.8	0.41	3.3	1.03	2.5	1.22	2.0	1.55	2	3	15.7		
2.3.3	75*	Chemical Oxygen-Iodine Laser Modeling	N	2.7	0.52	4.0	0.89	3.0	1.10	2.7	1.03	2	3	17.3		
2.3.3	78*	Semi-conductor Laser Analysis	N	3.0	0.89	3.3	0.82	2.8	0.98	1.5	0.84	2	3	15.7		
2.3.3	82*	Adaptive Optics Simulation	Y	3.2	1.47	3.5	1.05	2.7	1.37	2.8	0.98	2	2	16.2		
2.3.3	84*	Joint Modeling and Simulation System (J-MASS)	Y	3.6	0.74	3.0	1.20	4.1	1.36	2.3	1.04	1	3	17.0		
2.3.3	85*	Desktop M&S	Y	3.6	0.92	2.8	0.46	4.4	0.92	3.1	1.25	1	1	15.9		
2.3.3	86*	Collaborative Virtual Prototyping	Y	4.4	0.92	3.1	0.99	4.1	0.99	2.1	0.83	2	1	16.8		
2.3.3	90*	J-MASS Extensions For DoD HLA Interoperability	Y	4.1	1.25	3.6	0.52	3.1	0.64	2.1	0.64	1	3	17.0		
2.3.3	92	IRCM Modeling	N	3.1	0.99	4.6	0.74	2.9	0.35	1.6	1.06	3	2	17.3		
2.3.3	93	Modeling the Variability of IR Threat Systems	Y	3.0	0.00	3.8	1.39	3.0	0.87	2.1	1.27	3	2	16.9		
2.3.3	94	Advanced Modeling Methods	N	2.6	0.52	2.8	0.89	3.1	0.83	2.0	0.53	3	1	14.5		
2.3.3	95*	Thermal Simulations using the COYOTE Computer Code	N	2.3	0.50	2.0	0.82	2.3	0.50	2.0	0.82	2	1	11.5		
2.3.3	96*	Fire Modeling and Simulation	N	2.4	0.89	3.4	0.89	2.6	1.14	2.6	0.55	3	2	16.0		
2.3.3	98	Hearing Functional Evaulation	N	2.4	0.55	3.6	0.89	2.8	0.45	3.4	0.89	3	2	17.2		
2.3.3	102	Exploratory Modeling	Y	2.4	1.52	4.0	0.71	2.4	0.89	3.8	0.84	3	1	16.6		
2.3.3	105	Air Campaign Optimization	Y	3.5	1.07	2.1	1.25	2.5	0.76	1.5	1.07	2	3	14.6		
2.3.3	106	Genetic Algorithms	Y	2.7	0.52	2.2	0.41	3.0	0.89	2.7	1.03	2	2	14.5		
2.3.3	110*	Simulation of Lubricated Contacts and Dynamics of Rolling Element Bearings	N	2.7	1.03	2.5	0.55	2.7	1.03	2.0	1.26	2	2	13.8		
2.3.3		Epitaxial Growth Modeling	N	2.2	0.75	2.7	1.37	2.2	0.98	2.7	0.82	3	1	13.7		
2.3.3	112	Atomic-Level Modeling and Simulation of Materials	N	2.5	0.55	3.2	1.47	3.0	0.89	3.3	1.37	1	1	14.0		
2.3.3	113	Quantum Mechanical Calculations and Molecular Dynamics Simulations for Obtaining Non-Structural Material Properties	N	2.8	1.17	2.5	1.38	2.7	1.03	3.0	1.10	3	1	15.0		
2.3.3	114	Modeling of Composite Bolted Joints	N	2.5	0.84	3.2	0.98	2.8	1.17	2.2	1.17	2	1	13.7		
2.3.3	117	Nonlinear Indicial Response Modeling	N	2.5	0.84	3.7	1.03	3.0	0.00	3.3	0.82	3	1	16.5		
2.3.3	118	Flying Qualities of Manned Aircraft - Simulator Effectiveness and Required Techniques for Pilot Induced Oscillation (PIO) Studies	N	3.2	1.60	3.0	1.26	2.7	0.82	2.2	0.98	2	3	16.0		
2.3.3	120*	Subsystems Integrated Design Assessment Technology/Integrated Subsystems Interactions Tradeoff Evaluation (SIDAT/INSITE)	N	2.7	1.03	3.3	1.37	2.8	1.17	2.0	0.00	1	2	13.8		
2.3.3	121	Computational Fluid Dynamics (CFD) and Combustion	N	2.4	0.89	3.0	0.71	3.0	1.41	3.4	0.55	1	2	14.8		
2.3.3	122	Rolling Bearing Dynamics Simulation	N	2.0	0.71	2.4	0.55	1.8	0.45	1.8	0.84	3	1	12.0		
2.3.3	124	Modeling of visual discrimination with and without impairments	N	3.0	1.41	3.5	0.71	3.0	0.00	3.5	0.71	2	3	18.0		
2.3.3	128	High resolution microlaser based Helmet Mounted Display	N	2.5	0.71	4.0	0.00	3.0	0.00	3.0	1.41	3	2	17.5	15.4	1.9
2.3.4		**System Dynamics**														
2.3.4	55*	Dynamic simulation model of complex business system (major defense acquisition program)	Y	3.9	1.25	2.8	0.89	3.4	0.92	2.1	0.83	1	2	15.1		
2.3.4	73*	Trajectory analysis	Y	2.5	1.05	2.2	1.47	2.3	1.37	1.5	1.22	1	3	12.5		
2.3.4	77*	Airborne Laser Design	N	3.2	0.75	3.5	1.05	2.8	0.41	1.8	1.33	2	3	16.3	14.7	2.0
2.3.5		**Model Abstraction**														
2.3.5	7	Model Abstraction	Y	3.5	0.76	4.1	0.90	4.3	0.71	2.6	0.52	3	1	18.5		
2.3.5	24	Rational Functions in Metamodeling	Y	2.3	0.50	1.9	1.36	2.0	1.12	2.3	1.58	2	1	11.6		
2.3.5	10	Variable Resolution Modeling, Mixed Fidelity Simulation	Y	3.9	0.83	3.8	0.46	3.8	0.89	3.1	0.99	3	1	18.5		
2.3.5	17	Significant Event Detection (SigEvD) in Discrete-Event Simulation	Y	3.0	0.93	4.3	0.89	3.6	0.92	3.8	0.46	3	1	18.6		
2.3.5	21	Hierarchical Simulation and Statistical Fidelity	Y	3.3	0.71	4.3	0.89	3.5	1.07	3.0	1.20	3	1	18.0		
2.3.5	23	Neural Networks for Metamodeling	Y	2.7	0.49	3.7	1.25	3.3	0.49	3.4	0.79	3	1	17.1		
2.3.5	25	Fuzzy Discrete Event Systems M&S	Y	2.5	0.55	3.2	1.72	2.8	0.41	3.3	1.21	3	1	15.8		
2.3.5	26	Inductive Modeling/Soft Computing	N	1.9	0.69	2.6	1.27	2.3	0.95	3.6	0.79	3	1	14.3		
2.3.5	27	Fuzzy Systems	N	2.5	0.55	1.7	1.21	2.8	1.17	3.0	1.55	2	1	13.0		
2.3.5	28	General Information Theory (GIT)	N	2.2	0.41	4.2	0.75	2.3	0.82	4.2	0.41	3	1	16.8		
2.3.5	29	Fuzzy Modeling	N	2.2	0.41	3.5	1.22	2.7	1.03	3.5	1.05	2	1	14.8		
2.3.5	34	Quantification of fidelity. Relating simulator fidelity to counterpart operational system usage	N	2.8	0.75	3.5	0.84	3.5	0.55	2.8	0.75	2	2	16.7		
2.3.5	88	Resolution and Validation Manager	Y	3.0	0.00	3.3	0.71	3.6	0.73	2.6	0.73	2	2	16.4		
2.3.5	101	Multi-level and Cross Resolution modeling	Y	3.0	0.58	3.6	0.53	3.1	0.69	2.6	0.79	2	1	15.3		
2.3.5	30	Model Simplification through Formalism Transformation	Y	2.8	0.89	4.1	0.64	3.1	0.35	2.9	0.83	2	1	15.9		
2.3.5	53	Model Abstraction Via Solution of the Inverse Problem to Define a Reduced Order Model	Y	3.4	0.74	3.5	1.20	3.0	0.76	2.6	0.74	3	1	16.5	16.1	2.0

• APPENDIX C: AD HOC TEAM'S RATINGS SPREADSHEET

Pertinent Category	ET #	Responses: Title	Of potential use in Campaig Level Models	Importance Mear	Importance Standard Deviatio	Maturity Mear	Maturity Standard Deviatio	Potential for Development Mea	Development Potential Standar Deviatio	Science/Application Continuu Mea	Science/Application Continuu Standard Deviatio	Activity Mear	Uniqueness Mear	Composite Score (Sum of al factor rating scales	Subcategory Average Composit Scor	Subcategory Composite Scor Std Deviatio
			(Y/N)	(1-5)		(1-5)		(1-5)		(1-5)		(1-3)	1-3)			
2.4.1		**Design, Manufacturing, and Support Technology**														
2.4.1	4	Manufacturing control based on discrete event simulation	N	2.7	0.82	4.2	0.75	3.2	0.45	3.3	1.03	3	1	17.4		
2.4.1	41	Embedded training	N	3.3	0.76	2.7	0.76	3.3	0.49	2.4	0.79	2	2	15.7	16.5	1.2
2.4.2		**Exercise Management**														
2.4.2	46*	Exercise Management for Distributed Simulations	Y	3.0	0.00	2.1	0.90	3.3	1.11	2.0	1.00	2	1	13.4		
2.4.2	89	Exercise Management	Y	3.5	0.76	2.9	0.64	3.5	0.76	2.3	0.46	2	2	16.1		
2.4.2	103	Designing Virtual/Live/Constructive Simulation Experiments	Y	3.3	0.95	3.6	0.79	4.0	0.58	2.3	0.76	2	2	17.1		
2.4.2	128	High resolution microlaser based Helmet Mounted Display	N	2.5	0.71	4.0	0.00	3.0	0.00	3.0	1.41	3	2	17.5	16.0	1.8
2.4.3		**Man-In-the-Loop**														
2.4.3	1	Run-Time Adaptive Computer Interfaces	Y	2.7	0.82	2.0	1.10	3.0	1.10	1.8	0.75	3	1	13.5		
2.4.3	5	Real-time, man-in-the-loop weapon system simulation	Y	2.7	0.76	2.9	0.90	3.7	0.49	2.3	1.25	2	2	15.6		
2.4.3	103	Designing Virtual/Live/Constructive Simulation Experiments	Y	3.3	0.95	3.6	0.79	4.0	0.58	2.3	0.76	2	2	17.1		
2.4.3	119	Real-Time Piloted Engineering Flight Simulation	Y	3.8	1.39	2.8	1.39	3.1	1.25	2.0	1.20	2	3	16.6		
2.4.3	126	Human Performance Modeling	N	3.5	0.71	3.0	0.00	3.5	0.71	3.0	0.00	2	2	17.0	16.0	1.5
2.4.4		**Virtual Reality Technology**														
2.4.4	39	Three-dimensional, stereoscopic, pseudo-holographic, real-time display of computer generated imagery	Y	3.0	0.00	2.3	0.95	3.7	1.25	2.9	0.38	2	1	14.9		
2.4.4	103	Designing Virtual/Live/Constructive Simulation Experiments	Y	3.3	0.95	3.6	0.79	4.0	0.58	2.3	0.76	2	2	17.1		
2.4.4	116	Virtual Manufacturing	Y	3.4	0.92	2.9	1.25	2.9	0.99	2.1	0.64	1	2	14.3		
2.4.4	129	Microlaser based projection display for simulation	N	2.5	0.71	4.0	0.00	3.5	0.71	3.0	1.41	2	3	18.0		
2.4.4	130	A true three dimensional monitor for aerospace applications	N	2.5	0.71	3.5	0.71	3.5	0.71	2.5	0.71	3	2	17.0	16.3	1.6
2.4.5		**Simulation Paradigms**														
2.4.5	28	General Information Theory (GIT)	N	2.2	0.41	4.2	0.75	2.3	0.82	4.2	0.41	3	1	16.8		
2.4.5	8	Object-Oriented Model Engineering	Y	3.0	1.07	3.8	0.89	3.5	1.20	3.6	0.92	2	1	16.9		
2.4.5	9	Web-Based Simulation	Y	2.5	0.53	4.0	0.93	3.0	0.76	2.9	0.99	3	1	16.4		
2.4.5	10	Variable Resolution Modeling, Mixed Fidelity Simulation	Y	3.9	0.83	3.8	0.46	3.8	0.89	3.1	0.99	3	1	18.5		
2.4.5	12	Attributes Extrapolation under High Level Architecture (HLA)	Y	3.7	0.49	3.5	1.22	4.0	0.58	2.1	0.90	2	2	17.4		
2.4.5	13	Distributed Simulation of Heterogeneous Models	Y	2.6	1.27	4.9	0.38	2.6	1.27	3.7	0.76	3	1	17.7		
2.4.5	17	Significant Event Detection (SigEvD) in Discrete-Event Simulation	Y	3.0	0.93	4.3	0.89	3.6	0.92	3.8	0.46	3	1	18.6		
2.4.5	21	Hierarchical Simulation and Statistical Fidelity	Y	3.3	0.71	4.3	0.89	3.5	1.07	3.0	1.20	3	1	18.0		
2.4.5	26	Inductive Modeling/Soft Computing	N	1.9	0.69	2.6	1.27	2.3	0.95	3.6	0.79	3	1	14.3		
2.4.5	27	Fuzzy Systems	N	2.5	0.55	1.7	1.21	2.8	1.17	3.0	1.55	2	1	13.0		
2.4.5	30	Model Simplification through Formalism Transformation	Y	2.8	0.89	4.1	0.64	3.1	0.35	2.9	0.83	2	1	15.9		
2.4.5	31	Parallel simulation; the use of parallel and distributed platforms to execute discrete and continuous simulations	Y	3.6	0.79	2.4	1.27	3.4	0.79	3.0	1.00	2	1	15.4		
2.4.5	32	High Performance Parallel Discrete Event Simulation	Y	3.1	0.90	2.9	0.90	3.1	0.38	3.0	0.58	2	1	15.1		
2.4.5	35	Simulated environment interoperability between and among mixed fidelity simulators	Y	3.4	0.53	3.1	0.90	3.6	0.79	2.1	0.90	2	2	16.3		
2.4.5	40	Multi-Resolution Simulation	Y	3.5	0.53	4.1	0.83	3.4	0.92	2.5	0.53	2	1	16.5		
2.4.5	48	General Object Oriented Simulation Environment	Y	3.4	0.79	2.4	1.27	2.9	1.35	2.9	1.35	2	1	14.6		
2.4.5	52	Generative Analysis	Y	3.4	0.74	4.3	0.59	3.8	0.89	3.1	1.25	3	1	18.6		
2.4.5	54	Intelligent Simulation Objects	Y	3.3	0.76	3.9	1.07	3.4	0.53	3.0	0.00	2	1	16.6		
2.4.5	56	Object-Oriented Simulation	Y	2.9	0.38	3.0	1.00	3.6	0.79	3.0	0.58	2	1	15.4		
2.4.5	84*	Joint Modeling and Simulation System (J-MASS)	Y	3.6	0.74	3.0	1.20	4.1	1.36	2.3	1.04	1	3	17.0		
2.4.5	88	Resolution and Validation Manager	Y	3.0	0.00	3.3	0.71	3.6	0.73	2.6	0.73	2	2	16.4		
2.4.5	91*	Automated J-MASS Tools for DoD HLA Compliant Simulation Development	Y	3.5	0.76	3.9	1.25	3.5	0.76	2.3	0.89	1	2	16.1		
2.4.5	99	Cognitive Modeling	Y	2.9	0.90	3.1	0.69	3.3	0.49	3.9	0.38	2	1	15.9		
2.4.5	104	Generalized Networks Algorithms	Y	2.7	1.11	3.4	1.27	3.4	0.79	2.0	1.41	2	1	14.6		
2.4.5	108	Vestibular System Modeling	N	2.6	0.52	4.3	0.71	2.9	0.64	3.9	0.64	3	2	18.6		
2.4.5	117	Nonlinear Indicial Response Modeling	N	2.5	0.84	3.7	1.03	3.0	0.00	3.3	0.82	3	1	16.5		
2.4.5	29	Fuzzy Modeling	N	2.2	0.41	3.5	1.22	2.7	1.03	3.5	1.05	2	1	14.8		
2.4.5	33	Concurrent Simulation	Y	3.3	0.49	3.3	0.76	3.1	0.38	2.9	0.38	1	1	14.6		
2.4.5	47	Agent-based simulations of complex and complex adaptive systems	N	2.5	0.55	3.2	1.17	2.8	0.41	3.7	0.82	3	1	16.2		
2.4.5	70	Space Simulation Framework	N	3.3	0.95	2.6	0.98	3.0	1.15	1.9	1.21	2	3	15.7		
2.4.5	79*	Passive Scalar Models	N	2.8	0.98	3.2	0.98	2.8	1.47	2.8	0.98	2	2	15.7		
2.4.5	86*	Collaborative Virtual Prototyping	Y	4.4	0.92	3.1	0.99	4.1	0.99	2.1	0.83	2	1	16.8		
2.4.5	101	Multi-level and Cross Resolution modeling	Y	3.0	0.58	3.6	0.53	3.1	0.69	2.6	0.79	2	1	15.3		
2.4.5	115*	Modeling, Simulation, and Analysis (MS&A) Support to Aerospace Research and Acquisition	Y	4.1	0.99	3.3	1.16	3.8	1.39	1.8	1.39	1	3	16.9		
2.4.5	116	Virtual Manufacturing	Y	3.4	0.92	2.9	1.25	2.9	0.99	2.1	0.64	1	2	14.3		
2.4.5	123*	Conceptual Technology Integration	Y	3.4	0.79	3.6	0.79	3.3	0.95	1.4	0.79	2	3	16.7		
2.4.5	125	Decision Logic Design	N	2.0	0.00	3.0	1.41	3.0	0.00	3.5	0.71	2	2	15.5	16.2	1.3
2.5.1		**Computer Processing Speed**														
2.5.1	50*	High Performance Computing	Y	3.8	1.33	3.5	1.38	3.8	0.98	3.8	0.98	1	1	17.0		
2.5.1	71	Network-based distributed computing systems	Y	2.1	0.38	2.0	0.58	3.1	0.90	2.3	0.95	2	1	12.6	14.8	3.1
2.5.2		**Computer Storage and Retrieval**														
2.5.2	50*	High Performance Computing	Y	3.8	1.33	3.5	1.38	3.8	0.98	3.8	0.98	1	1	17.0	17.0	
2.5.3		**Desktop M&S**														
2.5.3	85*	Desktop M&S	Y	3.6	0.92	2.8	0.46	4.4	0.92	3.1	1.25	1	1	15.9		
2.5.3	131	PC based generator for flight simulation	N	2.5	0.71	2.5	0.71	3.0	0.00	2.5	0.71	2	1	13.5	14.7	1.7

Pertinent Category	No.	Responses: Title	Of potential use in Campaig Level Models (Y/N)	Importance Mear (1-5)	Importance Standard Deviatio	Maturity Mear (1-5)	Maturity Standard Deviatio	Potential for Development Mear (1-5)	Development Potential Standar Deviatio	Science/Application Continuu Mea (1-5)	Science/Application Continuu Standard Deviatio	Activity Mear (1-3)	Uniqueness Mear 1-3)	Composite Score (Sum of si factor rating scales	Subcategory Average Composit Scor	Subcategory Composite Scor Std Deviatio
2.5.4		**High Speed Data Transfer**														
2.5.4	32	High Performance Parallel Discrete Event Simulation	Y	3.1	0.90	2.9	0.90	3.1	0.38	3.0	0.58	2	1	15.1		
2.5.4	49	Representational Resolution and Fidelity	Y	3.5	0.76	3.8	0.89	3.8	0.71	2.9	0.83	2	2	17.9		
2.5.4	127	Data Warehousing	N	2.5	0.71	2.5	0.71	3.5	0.71	2.5	0.71	2	1	14.0	15.7	2.0
2.5.5		**Massive Parallel Processing**														
2.5.5	31	Parallel simulation; the use of parallel and distributed platforms to execute discrete and continuous simulations	Y	3.6	0.79	2.4	1.27	3.4	0.79	3.0	1.00	2	1	15.4	15.4	
2.5.6		**Object Oriented Principles**														
2.5.6	8	Object-Oriented Model Engineering	Y	3.0	1.07	3.8	0.89	3.5	1.20	3.6	0.92	2	1	16.9		
2.5.6	48	General Object Oriented Simulation Environment	Y	3.4	0.79	2.4	1.27	2.9	1.35	2.9	1.35	2	1	14.6		
2.5.6	51	Software Reuse via Composition	Y	2.9	0.35	3.5	0.93	3.5	0.76	3.1	0.35	2	1	16.0		
2.5.6	54	Intelligent Simulation Objects	Y	3.3	0.76	3.9	1.07	3.4	0.53	3.0	0.00	2	1	16.6		
2.5.6	56	Object-Oriented Simulation	Y	2.9	0.38	3.0	1.00	3.6	0.79	3.0	0.58	2	1	15.4	15.9	0.9
2.5.7		**Knowledge Compendium Tools**														
2.5.7	14	Database Support for Simulation Model	Y	2.9	0.69	3.6	0.79	2.6	1.27	3.7	0.76	2	1	15.7		
2.5.7	43	Calendaring via the World Wide Web (WWW)	N	1.7	0.76	2.4	1.51	2.6	1.13	2.0	1.00	2	1	11.7		
2.5.7	44	Document Collaboration via the World Wide Web (WWW)	N	2.0	0.82	1.8	0.96	1.8	0.96	2.3	1.26	2	1	10.8		
2.5.7	68	Decision Support System for Compliance	N	2.2	0.75	2.0	0.89	2.3	1.21	2.0	1.10	2	1	11.5		
2.5.7	100	Portable Neurological Function Automated Diagnostic Device	N	2.3	0.52	4.0	0.63	3.0	0.89	3.2	1.17	3	1	16.5	13.2	2.7
2.5.8		**Expert Systems**														
2.5.8	25	Fuzzy Discrete Event Systems M&S	Y	2.5	0.55	3.2	1.72	2.8	0.41	3.3	1.21	3	1	15.8		
2.5.8	26	Inductive Modeling/Soft Computing	N	1.9	0.69	2.6	1.27	2.3	0.95	3.6	0.79	3	1	14.3		
2.5.8	27	Fuzzy Systems	N	2.5	0.55	1.7	1.21	2.8	1.17	3.0	1.55	2	1	13.0		
2.5.8	29	Fuzzy Modeling	N	2.2	0.41	3.5	1.22	2.7	1.03	3.5	1.05	2	1	14.8		
2.5.8	100	Portable Neurological Function Automated Diagnostic Device	N	2.3	0.52	4.0	0.63	3.0	0.89	3.2	1.17	3	1	16.5		
2.5.8	109	Expert System Application to Computational Fluid Dynamics (CFD) Simulation Process	N	2.8	0.75	2.5	1.22	3.0	1.26	2.7	1.03	2	2	15.0	14.9	1.2

APPENDIX D: INDIVIDUAL ENABLING TECHNOLOGY SURVEY SHEETS

Enabling Technology #1: Run-Time Adaptive Computer Interfaces

Brief Description of the Technology Area: Run-time adaptive computer interfaces are defined as the ability to dynamically modify a shared memory interface to any application in order to connect two dissimilar applications in a new execution environment. This application is a process that allows for two applications with defined run-time interfaces, to be run-time modified to connect to each other and start the exchange of data. The real benefit of this enabling technology is the proof-of-concept and risk-reduction activities that need demonstrations of capabilities before further money and time is invested. This technology allows the application user to rapidly enhance any application by the integration with another application.

Degree of Maturity: This application is a currently available, commercial off-the-shelf application known as the Local Interfacing and Communications System (LINCS) version 2.2. This enabling technology is registered and has a patent pending with the U.S. Patent and Trademark Office, Washington DC.

Potential Air Force Application Area(s)/Benefit to the Air Force: This technology allows for extremely inexpensive mechanism for interfacing two applications in a proof-of-principle or risk-reduction activity.

Major Players/Leaders or Societies Doing Research in this Technology Area:

Daniel P. Schiavone, James Hooker, John Prikkel
Ball Aerospace and Technologies Corp.
2875 Presidential Dr., Suite 180
Fairborn Ohio 45324
Phone: (513) 320-4060
Fax: (513) 429-1687
E-mail: dschiavone@ball.com

Vision of Your M&S Technology: The vision of this technology is to allow "what if" games to be inexpensive and easily accomplished by a junior Engineer/Scientist with little application knowledge.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Daniel P. Schiavone
Same as above

Enabling Technology #2: Distributed Simulation Performance Modeling

Brief Description of the Technology Area: In an ever-increasing world of distributed real-time M&S, a systems performance model needs to be developed for all participating assets. The test manager can then execute the performance models and determine the overall distributed timing and performance of the exercise. This technology allows for life cycle support from helping to determining the performance requirements of an application, determining if a distributed exercise can perform well enough to accomplish the test objectives, all the way to helping to design a new USAF system. This enabling technology is applicable (and has been used in) all aspects of the M&S arena (constructive, virtual, MITL, HITL, and hybrids).

Degree of Maturity: System performance modeling is not a new technology in itself, but the development of a generic tool for distributed M&S performance modeling was recently completed. The architecture is now in place for a timing and sizing model to be developed for assets and be retained in a library.

Potential Air Force Application Area(s)/Benefit to the Air Force: This technology has an extremely wide application area in that all test managers requiring a distributed environment should first be assured the test can be achieved given the timing requirements and amount of data to be exchanged. This technology significantly reduces development and integration time/errors due to the gained knowledge of the modeled environment.

Major Players/Leaders or Societies Doing Research in this Technology Area:

Daniel P. Schiavone, Donald Bertke
Ball Aerospace and Technologies Corp.
2875 Presidential Dr Suite 180
Fairborn Ohio 45324
Phone: (513) 320-4060
Fax: (513) 429-1687
E-mail: dschiavone@ball.com

Vision of Your M&S Technology: The entire M&S community is striving for a modeling library where users can extract models based on their requirements. These models should be accompanied by a performance model that could be used by a user to determine if the model performs as needed.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Daniel P. Schiavone
Same as above

Enabling Technology #3: Dynamic Structure Modeling and Simulation

Brief Description of the Technology Area: Models whose structure changes while the simulation is running are the subject of this area. Such models include physical systems whose describing equations may change radically at discrete points, e.g., parachute; biological systems, such as growing plants; and social systems, such as self-organizing organizations. Although significant research has been done on such simulations, current simulation languages do not support them. To represent such changes they must be recast into parameter changes and this leads to a very convoluted code that is difficult to verify and inefficient to run. Augmenting current simulation languages, or introducing new ones, to support dynamic structure modeling would greatly increase the power of simulations to study complex structurally variable systems to gain true insight and predictability.

Degree of Maturity: This technology has been the subject of numerous investigations but only recently has a genuine theoretical framework been proposed and implemented. Thus research that can contribute to a coherent usable methodology is just at the initial phase.

Potential AF Applications: The simplest case exhibiting a variable structure occurs when a single component changes from one structure state to another. A much more complex situation occurs when the problem calls for creation, destruction, or modification of components during simulation. For example, modeling of flexible manufacturing systems requires components within a model to be assembled and disassembled. As indicated above, insertion of this technology would enable more credible, efficient and usable AF simulation models to be built. One area in particular that could greatly benefit is simulation support of AF business reengineering efforts, a major component of the AF's attempt to accommodate to shrinking budgets. To accurately represent the self-organizing formation of teams in dynamic business structures requires the full power of this technology.

Major Players/Leaders Doing Research in this Technology Area:

Bernard P. Zeigler, Hyup J. Cho, & Fernando Barros

References:

F.J. Barros, Dynamic Structure DEVS, Proceedings. 6th AI, Simulation and Planning in High Autonomy Systems, San Diego, CA., March 1996.

B.P.Zeigler & H. Praehofer, System Theory Challenges in the Simulation of Variable Structure Systems, CAST, Springer-Verlag, 1989

Name, Address, Phone Number, and E-mail:

Bernard P. Zeigler & Hyup J. Cho ECE Dept., University of Arizona
E-mail: zeigler@ece.arizona.edu hjcho@ece.arizona.edu Web: www.ais.ece.arizona.edu
Fernando Barros barros@mercurio.uc.pt

Enabling Technology #4: Manufacturing Control Based on Discrete Event Simulation

Brief Description of the Technology Area: Manufacturing control is traditionally approached with analytic/Markov methods for the creation of analytic models. However, using discrete event models to represent the machines, material handling, and input devices frees the modeler for experimentation with new and unique control methods. The primary focus of present work is to use "endomorphic" or internal model representation of the system within the controller, thereby facilitating decision making via simulation of actual scenarios. Because of the modularity of the approach, any of the existing online control elements including neural networks, fuzzy logic, or expert systems can be installed for performance analysis. This method frees the user to experiment with new, unproven approaches as well.

Degree of Maturity: While model-based control is intuitive and can represent the deep knowledge employed of a human expert charged with directing a process, the approach of applying discrete event simulation and the requisite large-scale computing for automation is still in its infancy. Further research is needed to bring it to the point where it can support manufacturing styles such as flexible or agile paradigms.

Potential Air Force Application Area(s)/Benefit to the Air Force: The Air Force has many manufacturing processes and similar processes, such as logistics repair, that could significantly benefit from agile or flexible design based on discrete event simulation.

Major Players/Leaders Doing Research in this Technology Area:
Jerry M. Couretas & Bernard P. Zeigler

Reference: B.P. Zeigler. DEVS representation of dynamical systems: Event-based intelligent control, Proceedings of the IEEE, 77(1):72-80, 1989.

Name, Address, Phone Number, and E-mail:

Jerry M. Couretas & Bernard P. Zeigler
Dept of Electrical and Computer Engineering
University of Arizona
Tucson AZ 85721
Phone: (512) 884-5362
E-mail: couretas@ece.arizona.edu
zeigler@ece.arizona.edu

Enabling Technology #5: Real-Time, Man-in-the-Loop Weapon System Simulation

Brief Description of the Technology Area: The Generic Electronic Combat Environment (GECE) simulation combines the principles of physics-based electronic combat simulation with the execution speeds required by real-time, man-in-the-loop applications. GECE uses the laws of physics and approved intelligence data to provide medium fidelity models of active and passive sensors, weapons, and countermeasures. The command and control structure is capable of representing both autonomous weapon systems and air defense control structures. Current research is focusing on making the transition from a closed system architecture to a DIS architecture while maintaining the fidelity and throughput requirements required for Combat Air Force Unit Training Devices (UTDs).

Degree of Maturity: This technology is currently being applied on the B-2 Aircrew Training Devices, and the F-16 and A-10 UTDs in the closed system architecture. It would take HRB Systems approximately 12 months to complete the transition of the GECE systems to a DIS architecture and complete a Contractor Engineering Verification Test CEVT of the DIS implementation.

Potential Air Force Application Area(s)/Benefit to the Air Force: Increased Electronic Combat fidelity provides increased ability to develop weapon system tactics that will prove effective in combat situations. The Combat Air Force believes that the GECE technology provides improved training capabilities over pervious technology. The expansion of this capability over DIS will improve the capability for team and interservice tactics training.

Major Players/Leaders Doing Research in this Technology Area:

Timothy S. Shaw
HRB Systems, Inc.
P.O. Box 60
State College PA 16804-0060
Phone: (814) 238-4311 Ext. 2068
E-mail: tss@icf.hrb.com

Name, Address, Phone Number, and E-mail of Person Providing This Input:

George A. Downsbrough
HRB Systems, Inc
P.O. Box 60
State College PA 16804-0060
Phone: (814) 238-4311 Ext. 3756
E-mail: gad@icf.hrb

Enabling Technology #6: Stochastic Layered Modeling

Brief Description of the Technology Area: Stochastic Layered Modeling (SLM) addresses the issue of multiple levels of resolution by providing a rapid mechanism to propagate stochastic distributions. If the interaction between components can be captured in a computational formula, this propagator can quickly estimate the resultant distribution from the parameter distributions of each of the components. When estimates and/or low resolution can be mixed with high resolution models, the low resolution ones typically have broader distributions than the high. The inclusion of these lower resolution components broadens the output distribution and proceeding to higher resolution versions will tighten the output. This has two aspects of importance to the M&S community: (a) models can be built with mixed resolution components, and (b) where there are resource constraints, models can initially be run with coarse components (which typically consume less resources) and as resources permit, run again with selected components at higher resolution. The user thus is assured an answer to work with that can get better as resources permit.

Degree of Maturity: A limited functionality version is currently in use by operational elements of Air Force Space Command for operational impact analysis. A fully functional version is expected to be fielded in early 1997.

Potential Air Force Application Areas: It is already in use by the Space community side of the Air Force and the fully functional version is eagerly anticipated by those elements. It could have similar impact for analogous issues in other Air Force Command communities.

Major Players/Leaders Doing Research in This Technology Area: Dr Thomas C. Fall, Senior Technologist, Lockheed Martin Space & Range Systems, is the architect for SLM and led the initial development efforts resulting in the current, limited version. Ms Mary Lou Benjamin, Kylix Associates, is the program manager of the development effort for the fully functional version (Dr Fall is providing consultative input for this.).

Name, Address, Phone Number, and E-mail:

Dr Thomas C. Fall
Lockheed Martin Space & Range Systems
1260 Crossman Avenue
Sunnyvale CA 94089-1198
Phone: (408) 734-6458
E-mail: tfall@srs.loral.com

Enabling Technology #7: Model Abstraction

Brief Description of the Technology Area: Model abstraction is the process of building a model hierarchy so that individual models relate to one another through structural or behavioral system equivalence. Two key types of abstraction have been identified: structural and behavioral. Structural abstraction aids in hierarchically building a system top down; each model layer relates to the one above it through a homomorphic relation. Behavioral abstraction is where we relate one model to another by virtue of their input-output behavior without concern for structure preservation. Today, simulation models are built using one model type and behavioral abstraction is not built into simulation software packages. Some multilevel modelers are available but the advantage of heterogeneous techniques such as multimodeling is that they allow different abstraction levels to be built using different model types. Model types are, frequently, good at representing a limited range of abstractions so one type by itself is insufficient for all levels.

Degree of Maturity: The technology is currently being applied in distributed interactive simulation, especially in the aggregate-level model protocol and for computer-generated force development when forces of different levels (i.e., company vs battalion) are present.

Potential Air Force Application Area(s)/Benefit to the Air Force: Model abstraction has two benefits, each relating to the abstraction type: (1) structural abstraction enables the creation of multilevel military tasks and unit behavioral modeling with interlevel consistency, and (2) behavioral abstraction permits a military model component to be simplified so that it takes less time to simulate. The tangible benefits of a more hierarchical modeling methodology and decreased computation time directly affect various military areas: speeding computer- generated force simulation, and easing the engineering process for coupling constructive and virtual simulations.

Major Players/Leaders Doing Research in this Technology Area:

Dr Paul A. Fishwick
Dept of Computer and Information Science and Engineering
University of Florida, Bldg CSE, Room 301
Gainesville FL 32611
Phone and Fax: (352) 392-1414
E-Mail: fishwick@cise.ufl.edu
Others: Dr Bernard P. Zeigler (Arizona) and Don Caughlin (Mission Res. Corp.)

Comments: The multimodeling approach (enabling structural abstraction), combined with behavioral abstraction methods, are currently being integrated within the University of Florida MOOSE system (Multimodeling Object-Oriented Simulation Environment). MOOSE enables graphical modeling of object dynamics using multi-models, and incorporates a scenario window for viewing an animation and setting initial conditions and parameters for the experimental design used to execute the simulation. Information on multimodeling and MOOSE can be found in http://www.cis.ufl.edu/~fishwick.

Enabling Technology #8: Object-Oriented Model Engineering

Brief Description of the Technology Area: Object-oriented (OO) program design and implementation has resulted in more efficiently designed and reused simulation components. We are constructing a toolkit called SimPack which supports multimodel construction. While the general field of OO simulation might be considered to be fully mature, there are disparate attempts in the simulation community to create object-oriented simulation without a clear engineering approach to building models. The emerging area of "model engineering" is as significant a method as "software engineering." That is, how do we create models step-by-step? A plethora of model types and object-oriented approaches exist. In a recent text (Fishwick), we propose an engineering approach and taxonomy for model construction. Instead of proposing yet another model type, a "glue" mechanism for integrating existing model types is provided. Moreover, we developed an engineering method for logically constructing models given initial information and knowledge base about a physical system that includes a method for integrating dynamics and geometry for OO models. "Dynamics" refers to simulation models, and "geometry" refers to spatial data structures (often used in computer-aided design and computer graphics).

Degree of Maturity: The base OO technology is mature but a clear engineering approach to model construction given a physical system is unclear, and there are many unrelated approaches. A good set of base OO programming languages such as C++, SmallTalk, Java, and Dylan exist.

Potential Air Force Application Area(s)/Benefit to the Air Force: The military currently supports a wide variety of simulation models and programming languages, but the lack of a clear engineering approach to OO model construction has caused a lack of connectivity among researchers and practitioners. Object-oriented model engineering has the potential to benefit all areas of Air Force simulation by promoting a "way of thinking" about physical objects, as well as the dynamic and geometric models embedded in these objects. The formation of a subdiscipline for model engineering will help simulationists to coordinate their modeling efforts.

Major Players/Leaders Doing Research in this Technology Area:

Dr Paul A. Fishwick
Dept of Computer and Information Science and Engineering
University of Florida, Bldg CSE, Room 301
Gainesville FL 32611
Phone and Fax: (352) 392-1414 E-Mail: fishwick@cise.ufl.edu

Others: Dr Bernard P. Zeigler (Arizona), Dr Tag-Gon Kim (KAIST)

Comments: Our basic approach to simulation modeling and engineering of OO models can be found in a publications area: http://www.cis.ufl.edu/~fishwick/tr/tr.html. The SimPack toolkit is documented in http://www.cis.ufl.edu/~fishwick/simpack/simpack.html. We are currently writing a report on the comprehensive approach to OO model engineering. This approach is based partly on a recent book "Simulation Model Design & Execution" whose first chapter can be found on the web: http://www.cis.ufl.edu/~fishwick/tr/books.html.

Enabling Technology #9: Web-Based Simulation

Brief Description of the Technology Area: The World-Wide Web (WWW) has had a significant influence on the way in which we view and manipulate information on the Internet. Web-based simulation is a new area where computer simulation models execute, often in a distributed fashion, over the Internet. Web-based simulation relies upon several related technologies including hypertext, multimedia, networking, and distributed processing. The way we do simulation now is to build a model or simulation on one computer and then execute that model. The simulation field must keep pace with the fast-moving web technology. An emphasis on web-based simulation will increase the exposure of simulation in general, and make the output from simulation more accessible to everyone.

Degree of Maturity: The technology underlying web-based simulation is mature but the field of web-based simulation is in its infancy. Therefore, the time is ripe to take advantage of the technology so that an integrated web-based M&S foundation can be successful.

Potential Air Force Application Area(s)/Benefit to the Air Force: There are several military areas that will benefit from an emphasis in this field. A key benefit area is in the use of simulations for nontraining purposes. For instance, if we consider computer-aided instruction for military tasks and education, web-based simulation can create a widely accessible tool for all military personnel. Moreover, web-based simulation can be used in military acquisition and training phases. For training, it is feasible to embed a DIS protocol enabled by Java so that interactive simulations can take place.

Major Players/Leaders Doing Research in this Technology Area:

Dr Paul A. Fishwick
Dept of Computer and Information Science and Engineering
University of Florida
Bldg CSE, Room 301
Gainesville FL 32611
Phone and Fax: (352) 392-1414
E-Mail: fishwick@cise.ufl.edu
Others: Refer to the hotlist http://www.cis.ufl.edu/~fishwick/hot1ist.html in "Web-based Simulation" for examples.

Comments: We created an early interactive simulation paper prior to the invention of the Java language. The paper can be found at: http://www.cis.ufl.edu/~fishwick/cpudisk. The paper involves both a description of simulation modeling in SimPack and cgi-bin scripts for the execution of the simulation. We currently have one Master's student doing his thesis on web-based simulation. One Hybrid Monte Carlo simulation was done as part of our Advanced Simulation Course (CAP 6836). See http://www.cis.ufl.edu/~thorndyke/hmcdemo.html for this example.

Enabling Technology #10: Variable Resolution Modeling, Mixed Fidelity Simulation

Brief Description of the Technology Area: Model abstraction: Model abstraction refers to the process of creating a computationally simpler model from a more complex model without changing the results of the model with respect to a specific simulation requirement. A number of model abstraction approaches were grouped into three basic categories: (a) techniques that simplify by eliminating an input factor; (b) techniques that simplify by aggregating key aspects of the model, resulting in fewer potential system states; and (c) techniques that modify the fundamental computational form of the model (e.g., deterministic to stochastic). In some cases, the techniques are commonly applied, but in an ad hoc, rather than methodical, approach. In other cases, the techniques are still being researched and provide potentially significant reductions in simulation complexity when addressing specific simulation requirements. In terms of impact to the modeling and simulation community, the primary payoff of model abstraction is in modularly constructed simulation models which can be rapidly configured and "tuned" to perform only the computations necessary to generate specific data. This approach contrasts to today's practice of building computationally complex models designed to respond to vast arrays of simulation requirements; i.e., universality at the cost of efficiency.

Degree of Maturity: The individual techniques range from commonly practiced to current research. It is only recently that attempts have been made to bring together various techniques into a unifying concept of model abstraction. Some specific aspects of this concept, such as using different representations of models to identify potential abstractions (surrogate abstraction domains), still require research to formalize their definition and application.

Potential Air Force Application Area(s)/Benefit to the Air Force: There are a number of areas this technology could specifically benefit. First, model abstraction techniques can be used to reduce the computational complexity of simulation models, resulting in lower execution time, lower data collection and verification time, and lower data analysis time. Second, the technology can be applied in cases where legacy models of different resolution are being integrated. A more abstract model of a particular entity or process can be compared to a more detailed model to determine whether it is a valid abstraction of the detailed model. If (and after modification, when) it is, the simpler model can be substituted for the more detailed model without altering simulation results. Third, incremental validation can be accomplished by applying valid abstractions to valid models, without having to revalidate the entire resultant model.

Major Players/Leaders in This Technology Area: Basic concepts developed by Fred Frantz; related research being performed by Dr Paul Fishwick, University of Florida, and Dr Bernard Zeigler, University of Arizona.

Comments: A report will be published soon as a Rome Laboratory Technical Report.

Name, Address, Phone Number , and E-mail:

Mr Fred Frantz, NYSTEC, 28 Electronics Parkway, Rome NY 13441
Phone: 315-338-5818 E-mail: frantz@syrres.com

Enabling Technology #11: Small Team Situational Training and Mission Planning / Rehearsal

Brief Description of the Technology Area: Use of simulation (virtual reality) to train, plan, and rehearse small team operations.

Uniqueness:

1. Level of complexity. This work incorporates intelligent, virtual people in order to simulate close quarters operations. Virtual actors may be controlled real time during a simulation to allow dynamic outcomes.

2. Scenario authoring. This work is developing a capability to allow scenarios to be developed quickly by allowing scripts to be attached to virtual actors via a graphical user interface. Scripts may be invoked during a simulation at any time.

3. Participant representation: This work is developing techniques to allow participants in a simulation to be seen as full human figures with enough fidelity to provide body language and gesture representation.

4. Interactivity. This work is developing integrated interactivity with a simulation at many levels (teams of participants, virtual actors and other "animate objects," and tutoring and performance feedback tools).

Degree of Maturity: A limited version of this work is available for field testing. Timeline for development depends upon the complexity of the task to be trained. Prototypes currently exist for conventional battlefield medic training (primary assessment of wound), and for antiterrorist mission planning (room clearing operation).

Potential Air Force Application Area(s)/Benefit to the Air Force: Direct application to Air Force needs might include medic training, maintenance, and operations other then war.

Major Players/Leaders Doing Research in this Technology Area: University of Pennsylvania (Dr Norman Badler); Naval Postgraduate School (Dr Mike Zyda); similar, but simpler, work in semi-autonomous forces (e.g., DARPA programs) is also somewhat related.

Comments: See our web page for more details and for a bibliography of papers relating to this work: http://www.sandia.gov/vris/vris_homepage.html

Name, Address, Phone Number, and E-mail:

Dr Sharon Stansfield, Sandia National Laboratories
P.O. Box 5800, MS 0978
Albuquerque NM 87185-0978
Phone: (505) 844-1396
Fax: (505) 844-2057 E-mail: sastans@sandia.gov

Enabling Technology #12: Attributes Extrapolation under High Level Architecture (HLA)

Brief Description of the Technology Area: In Distributed Interactive Simulation (DIS), the entity states are sent in the form of standard protocols, called Protocol Data Unit (PDU). Each field in a PDU is well defined in the DIS standard. There is very little flexibility in passing and extrapolating parameters other than the ones defined in the standard. Under High Level Architecture (HLA), each Federation can decide its own rules. Therefore, it becomes very flexible in passing and extrapolating parameters, or attributes, as HLA uses Object-Oriented Approach. Attributes extrapolation can be used to reduce network traffic and make distributed simulation possible.

HLA has become a mandate in the government M&S programs. The research efforts in attributes extrapolation is vital to the success of HLA in distributed simulation, just like the Dead Reckoning algorithm was vital to the success of DIS.

Degree of Maturity: The research on HLA-related issues has just begun last year. However, since IST has a lot of experience in DIS/Dead Reckoning as well as HLA Proto-Federation development, I believe the technology is already mature for application in Air Force programs.

Potential Air Force Application Area(s)/Benefit to the Air Force: This technology can be applied to virtually all Air Force M&S areas, especially all programs related to distributed simulation.

Major Players/Leaders Doing Research in this Technology Area:

Dr Kurt Lin
Associate Professor of Aerospace Engineering
Institute for Simulation and Training
Phone: (407) 658-5029
E-mail: klin@pegasus.cc.ucf.edu

Mr Mikel D. Petty
Program Manager
Institute for Simulation and Training
Phone: (407) 658-5022
E-mail: mpetty@ist.ucf.edu

Name, Address, Phone Number, and E-mail:

Dr Kurt Lin
Associate Professor of Aerospace Engineering
Institute for Simulation and Training
3280 Progress Drive
Orlando FL 32826
Phone: (407) 658-5029
E-mail: klin@pegasus.cc.ucf.edu

Enabling Technology #13: Distributed Simulation of Heterogeneous Models

Brief Description of the Technology Area: Current Distributed Interactive Simulation (DIS) protocols do not provide for strict global time preservation among federated models. This motivates the development of a methodology for distributed simulation of discrete event models written in different simulation languages/environments that preserves strict time correspondence. DEVS (Discrete Event Systems Specification) models are used as a common communication means. We propose a software bus called DEVS bus and an associated protocol to provide an interface between DEVS models and non-DEVS models such as SIMSCRIPT, MODSIM, SLAM models, and so on. Proposed also are protocol converters which support communication standard for non-DEVS models. The methodology can be implemented using a network programming language such as JAVA.

Degree of Maturity: No methodology or simulation environment described above has been proposed.

Potential Air Force Application Area(s)/Benefit to the Air Force: Insertion of this technology would provide great benefits to the Air Force in network-based distributed simulation of a large-scale system in which models of subsystems are developed in different languages/environments. It significantly reduces model development by reuse of existing heterogeneous models.

Major Players/Leaders Doing Research in this Technology Area:

Dr Tag Gon Kim
Department of Electrical Engineering
Korea Advanced Institute of Science and Technology
Taejon 305-701, Korea
Phone: +82-42-869-3454
E-mail: tkim@ee.kaist.ac.kr

Enabling Technology #14: Database Support for Simulation Model

Brief Description of the Technology Area: Large-scale, complex systems modeling often requires management of simulation models in an organized library or database. One major reason advantage is the potential for reuse of component models at different subsystems levels. Such model management can be effectively supported by employing object-oriented database technology. In this technology, a system can manage not only model structure in the form of coupling relations between component models, but also model behavior in the form of source codes or compiled codes. Such coupling relations and/or behavioral codes can be reused later on as building blocks to build larger models.

Degree of Maturity: This technology area has already successfully been applied in the development of an intelligent simulation environment. However, much research has to be done in order to apply the technology in the real world. For example, we need to develop a method for generating simulation models residing in an object-oriented database from modeling requirements and objectives.

Potential Air Force Application Area(s)/Benefit to the Air Force: Insertion of this technology would provide great benefits to the Air Force in large-scale, complex systems modeling, simulation, and analysis. It significantly reduces model development time by an efficient reuse of existing simulation models as building blocks.

Major Players/Leaders Doing Research in this Technology Area:

Dr Tag Gon Kim
Department of Electrical Engineering
Korea Advanced Institute of Science and Technology
Taejon 305-701, Korea
Phone: +82-42-869-3454
E-mail: tkim@ee.kaist.ac.kr

Enabling Technology #15: Unified Framework for Design and Implementation of Discrete Event Systems

Brief Description of the Technology Area: The design of a discrete event control system usually employs discrete event simulation to verify functional requirements as well as to evaluate performance. Such simulation can be performed in discrete event simulation languages. Once simulation is done, the implementation of the designed discrete event system may proceed using a programming language, such as C or C++, which can be executed in real time. Since source code implementation totally differs from that of the simulation model, this approach to design cannot reuse the simulation model code in implementation. An ideal environment supports a close relation between simulation model and implementation code. In such an environment, a set of operating system-like system functions support execution of a simulation model in real time. Thus, the same model analyzed in simulation can later be converted to real-time execution in a near seamless manner.

Degree of Maturity: No unified framework to realize the above concepts has been reported.

Potential Air Force Application Area(s)/Benefit to the Air Force: Insertion of this technology would provide great benefits to the Air Force in discrete event systems design and implementation. It significantly reduces systems development time by using simulation models in real-time execution without any change.

Major Players/Leaders Doing Research in this Technology Area:

Dr Tag Gon Kim
Department of Electrical Engineering
Korea Advanced Institute of Science and Technology
Taejon 305-701, Korea
Phone: +82-42-869-3454
E-mail: tkim@ee.kaist.ac.Kr

Enabling Technology #16: Simulation Query Language for Knowledge-Based Systems

Brief Description of the Technology Area: Simulation results give rise to large databases with very specific structures. In particular, these databases are dynamic in the sense that they are constantly changing as better statistical accuracy is achieved or additional input-output relationships explored. Similar to standard database management languages (e.g., SQL) which have dramatically enhanced the use of conventional databases, a Simulation Query Language is a specialized language for interacting with any underlying simulator.

Significance to the M&S Field: (a) A simulation query language enables the systematic organization of simulation data and hence fast and effective interaction with the underlying simulator, and (b) a simulation query language is the tool that will enable the incorporation of simulation into Knowledge-Based Systems which, up to this point, lack that capability despite the importance of simulation to any such system.

Degree of Maturity: Only preliminary attempts at development of simulation query languages have been made despite the natural need for them as a parallel to conventional database query languages, and the call for such query languages from the knowledge-based system community. This technology is in its infancy. Projected time to maturity is 2-3 years for a robust prototype.

Potential Air Force Application Area(s)/ Benefit to the Air Force: This technology will benefit any Air Force activity that involves simulation or the use of knowledge-based systems. It will make simulation largely transparent to the user, thus greatly extending its applicability to a nonexpert community.

Major Players/Leaders Doing Research in this Technology Area:

Christos G. Cassandras
Dept of Electrical and Computer Engineering, University of Massachusetts
Amherst, MA 01003
Phone: (413) 545-1340 E-mail: cassandras@ecs.umass.edu

Wei-Bo Gong
Dept of Electrical and Computer Engineering, University of Massachusetts
Amherst, MA 01003
Phone: (413) 545-0384 E-mail: gong@ecs.umass.edu

Comments: The development of a Simulation Query Language will require interdisciplinary collaboration among experts in simulation, software engineering, and artificial intelligence.

Name, Address, Phone Number, and E-mail:

Christos G. Cassandras and Wei-Bo Gong
Same as above.

Enabling Technology #17: Significant Event Detection (SigEvD) in Discrete-Event Simulation

Brief Description of the Technology Area: Any large-scale simulation is, by definition, complex to analyze due to size and diversity of the data. Events (in discrete-event simulations) represent a set of states (in one or more models) that are capable of influencing states of other models in the environment. Therefore, an event may be determined as significant based on values of specific state variables (in one or more models). Significant events are thus said to occur in a time period when a predefined set of conditions is met by a subset of the variables in the simulation. The user defines what he considers to be a significant event using primitives and model parameters before simulation. At run-time, event detectors sift through data looking for significant events. This enables users/model developers to effectively pursue their goal (conceptual or analytical). In essence, SigEvD allows any large-scale simulation to be viewed at various levels of abstraction where level of abstraction is determined by significance of the event.

Degree of Maturity: This technology is a result of efforts to effectively handle large quantities of spatial/DIS data used in large-scale ecosystem simulations. While a good working design and understanding of the system has been formulated, further research and development is required for implementation and seamless integration into a modeling and simulation methodology.

Potential Air Force Application Area(s)/Benefit to the Air Force: Due to the size and/or complexity of most Air Force simulations, this technology would impact virtually all application areas where modeling and simulation is used. Being generic in nature, the concept could be modularized as an independent entity in diverse discrete-event simulations. In battle simulations where planning, resource and personnel deployment, and communication are independent entities, there is too much data to track. The same model can be used by commanders in charge of each of the battle spaces where a significant event for one may or may not be a significant event for another, radically reducing their output data set.

Major Players/Leaders Doing Research in this Technology Area: Although there are several people working on data reduction/abstraction methods, we are unaware of research in significant event detection in large simulation from a discrete-event standpoint.

Comments: This technology has only been recently developed and has no direct citations. Some of the formalization of this work was included in a talk given by Sankait Vahie at Hewlett Packard Labs in Palo Alto, CA.

Name, Address, Phone Number, and E-mail:
Sankait Vahie & Bernard P. Zeigler
AI & Simulation Labs, Dept of Electrical & Computer Engineering
University of Arizona
Tucson AZ 85721
Phone: Office (520) 621-2108; Lab (520) 621-6184
E-mail: sankait@ece.arizona.edu
zeigler@ece.arizona.edu

Enabling Technology #18: Automatic Model Verification

Brief Description of the Technology Area: Automatic Model Verification (AMV) differs from the conventional model verification methods in which verification is based on manually executed simulation runs. AMV aims toward automation of discrete event models verification based on a dual specification approach. The approach employs two specifications for a discrete event model: an operational specification for the behavior of a model and an assertional specification for its temporal properties. A model's verification is based on a language acceptance checking mechanism for which the assertional model constitutes a language grammar and the operational model acts as string generators.

Degree of Maturity: Promising research in this technology has been performed. Although no software tool for AMV based on the dual specification approach has yet been developed, a prototype has successfully demonstrated the approach. Further research and development is needed to reduce the approach to usable tools.

Potential Air Force Application Area(s)/Benefit to the Air Force: Insertion of this technology would provide great benefit to the Air Force for every modeling and simulation application. It can significantly reduce verification and debugging time for large models.

Major Players/Leaders Doing Research in this Technology Area:

Dr Tag Gon Kim
Department of Electrical Engineering
Korea Advanced Institute of Science and Technology
Taejon 305-701, Korea
Phone: +82-42-869-3454
E-mail: tkim@ee.kaist.ac.kr

Enabling Technology #19: Experimental Frame Methodology

Brief Description of the Technology Area: Experimental frames enable simulationists to translate the objectives and issues to be addressed by a modeling effort into conditions under which a model or real system will be experimented with. As a major part of initial requirements specification, experimental frames are critical to appropriate choices (such as level of resolution, accuracy, etc.) throughout the subsequent modeling and simulation effort. Experimental frames map into modules that actually do the experimentation (input generation, output summarization, etc.) when models/systems are operable.

Degree of Maturity: While the concept of experimental frames has been around for some time, it is only recently that full support for their specification, manipulation, and management has been attempted. Experiment plans are supported in a Bomb Damage Assessment environment. However, such plans are formulated after model development, rather prior to it, as in true experimental frames. Some current environments support experimental frame construction as executable components but do not support the more abstract specification needed for symbolic manipulation.

Potential Air Force Application Area(s)/Benefit to the Air Force: AF modeling and simulation efforts often are overly costly due to their inability to make critical choices such as scope of representation and resolution level that should be driven by issues- oriented experimental frames specified in advance of the model building. Moreover, the archiving of experimental frames and matching them with existing models enables a high level of reuse of models.

Major Players/Leaders Doing Research in this Technology Area:

Dr Bernard Zeigler

Name, Address, Phone Number, and E-Mail:

Dr Bernard Zeigler
Dept of Electrical and Computer Engineering
University of Arizona
Tucson AZ 85721
Phone: (520)-621-6184
Fax: (520)-621-3862
E-Mail: http://www-ais.ece.arizona.edu/-hessam

Enabling Technology #20: Graphical Description of Discrete Event Models Behavior

Brief Description of the Technology Area: Many good graphical tools are in place for discrete event systems modeling. Such tools use icons to represent predefined models, most of which support users to add a new model definition and an associated icon to the existing library. However, little has been done in graphical notation for behavioral description of discrete event models. An excellent example for such notation in discrete event modeling is a stochastic Petri Nets graph. In spite of its generality in modeling, stochastic Petri Nets are limited to modeling certain classes of discrete event systems. Thus, a graphical notation based on sound semantics, which is easy to use and understand, needs to be developed for the rapid and accurate modeling of discrete event systems. The graphical notation should include such information as state transition function, output function, and sojourn time function for a basic component of a discrete event process. Of course, the graphical notation should generate executable simulation codes.

Degree of Maturity: No graphical tool to model behavior of general discrete event models has yet been released in the commercial domain.

Potential Air Force Application Area(s)/Benefit to the Air Force: Insertion of this technology would provide great benefits to the Air Force in large-scale, complex models development. It significantly reduces models development time.

Major Players/Leaders Doing Research in this Technology Area:

Dr Tag Gon Kim
Department of Electrical Engineering
Korea Advanced Institute of Science and Technology
Taejon 305-701, Korea
Phone: +82-42-869-3454
E-mail: tkim@ee.kaist.ac.kr

Enabling Technology #21: Hierarchical Simulation and Statistical Fidelity

Brief Description of the Technology Area: Many simulation models, and combat simulation models in particular, have a distinct hierarchical structure. The lower, high resolution-level simulator generates reports which are then taken as inputs for the higher level simulator. Current practice is to use the mean values of variables from the lower level reports as the input to the higher level. This implies that significant statistical information (i.e., *statistical fidelity*) is lost in this process resulting in potentially completely inaccurate results. Especially when the ultimate output of the simulation process is of the form 0 or 1 (e.g., "lose" or "win" a combat), such errors can provide the exact opposite of the real output. This technology provides an interface between the two simulation levels to preserve the statistics to the maximum extent that the available computing power allows. The use of a clustering neural network enables the development of such an interface.

Significance to the M&S Field: Enables handling very large-size, hierarchical simulation models with significantly more accuracy.

Degree of Maturity: The basic idea is clearly applicable to many systems. For each concrete application, one needs to work on the specific details.

Potential Air Force Application Area(s)/Benefit to the Air Force: Any hierarchical simulation model analysis of interest to the Air Force will benefit from this technology. The most obvious application area is in Combat Simulation.

Major Players / Leaders Doing Research in this Technology Area:

Wei-Bo Gong
Dept of Electrical and Computer Engineering
University of Massachusetts
Amherst MA 01003
Phone: (413) 545-0384
E-mail: gong@ecs.umass.edu

Christos G. Cassandras
Dept of Electrical and Computer Engineering
University of Massachusetts
Amherst MA 01003
Phone: (413) 545-1340
E-mail: cassandras@ecs.umass.edu

Name, Address, Phone Number, and E-mail:

Christos G. Cassandras - Same as above

Wei-Bo Gong – Same as above

Enabling Technology #22: Advanced M&S Environments for Intelligent and Cognitive Systems

Brief Description of the Technology Area: Building models of intelligence, perception, and human performance have proved to be difficult due in part to the uncertainty in the psychophysiological theories proposed to explain behavioral phenomenon. The Successive Approximation Methodology (SAM) supports intelligent and cognitive model development using an incremental refinement approach [1]. It also provides the ability to develop multiresolution models. Recent developments in neuroscience have enabled us to envision behavior as a synergistic result of biological cells--neurons. Dynamic Neural Ensembles (DNEs) provide a dynamic environment and the components necessary for the development of highly complex cognitive models aggregating cellular behavior to represent intelligence and learning. DNEs are compositions of interconnected dynamic neurons. At a more abstract level, "holon" hierarchy models are being developed. Simulation environments supporting such models use object-oriented programming techniques to provide ease of parameter modification and specialization of both behavior and structure.

Degree of Maturity: The Successive Approximation methodology was developed in cooperation with Mike Young (Wright-Patterson AFB OH). A report was submitted to BBN Inc. referencing work done on this methodology [4]. An implementation and incorporation of this methodology into an M&S environment is still pending [1],[3]. The DNE is being developed by Sankait Vahie [2]. Applications of DNEs to real-time learning, control, and decision making are currently being pursued. The OMAR environment has been developed to support holon hierarchical models.

Potential Air Force Application Area(s)/Benefit to the Air Force: USAF systems and component designs for the 21st Century will have to increasingly address the issue of human operability and performance. The development of autonomous systems capable of functioning in dynamic environments is also an issue of interest. The first issue, operability and performance, requires an approach that needs to be seamlessly integrated into design. The successive approximation provides a methodology for integration of cognition and intelligence into the systems design. New forms of neural and cognitive models, capable of dynamic behavioral modification, need to be explored to adequately capture flexible behavior.

Major Players/Leaders Doing Research in this Technology Area:

Mike Young
AFRL/HE
2696 G Street
Wright-Patterson AFB OH 45433-7605.

Bolt, Baranek, & Neumann (BBN) Systems & Technologies Inc.
Cambridge MA 01730

Sankait Vahie and Bernard P. Zeigler, University of Arizona

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Name, Address, Phone Number, and E-mail:

Sankait Vahie & Bernard P. Zeigler
AI & Simulation Labs
Dept of Electrical & Computer Engineering
University of Arizona
Tucson AZ 85721
Phone: Office (520) 621-2108
Phone: Lab (520) 621-6184
E-mail: sankait@ece.arizona.edu
zeigler@ece.arizona.edu

Enabling Technology #23: Neural Networks for Metamodeling

Brief Description of the Technology Area: For extremely complex systems, simulation models become hopelessly slow to run and difficult to interact with. Metamodeling is the process of abstracting key elements of a system's behavior to produce a final model which is much simpler and easier to use, yet maintains reliable levels of accuracy when used for design or decision making purposes. Traditional techniques to obtain such metamodels have relied largely on linear regression methodologies using polynomial functions to approximate complex system input-output relationships. However, systems developed with today's technology exhibit behavior dramatically more complex than polynomial approximations can capture. Neural networks are models which can capture arbitrarily complex system behavior. Though the term "neural network" invokes images of a complex biological structure, in fact, a neural network is a mathematical model readily implementable in software. It consists of interconnected units called "neurons" with "weights" associated to them. By adjusting these weights, a neural network output functions of great generality that can capture the input-output relationships of complex systems typically modeled through simulation.

Significance to the M&S Field: Enables generation of a metamodel with significantly greater accuracy than conventional methods, and the neural network's inherent parallelism enables the modeling of extremely large systems that are otherwise impossible to model in any other way.

Degree of Maturity: Neural network technology was introduced into commercial applications over the past several years and celebrated as revolutionary in such fields as pattern recognition and automatic speech synthesis, however, the idea of utilizing neural networks in conjunction with simulation for metamodeling purposes is very new. Significant research is needed to lead this to a mature technology over the next 2-3 years.

Potential Air Force Application Area(s)/ Benefit to the Air Force: Any complex system design effort of interest to the Air Force will benefit from neural network metamodeling technology. The most obvious application area is in Combat Simulation.

Major Players/Leaders Doing Research in this Technology Area:

Wei-Bo Gong
Dept of Electrical and Computer Engineering, University of Massachusetts
Amherst MA 01003
Phone: (413) 545-038
E-mail: gong@ecs.umass.edu

Christos G. Cassandras
Dept of Electrical and Computer Engineering, University of Massachusetts
Amherst MA 01003
Phone: (413) 545-1340
E-mail: cassandras@ecs.umass.edu

Enabling Technology #24: Rational Functions in Metamodeling

Brief Description of the Technology Area: Polynomial functions are frequently inadequate in capturing the behavior one often encounters in simulation models. A richer class is that of *rational* functions. A polynomial function is of the form $P_n(x) = a_0 + a_1x + a_2x^2 + \ldots + a_nx^n$. A rational function is of the form $R_{nm}(x) = P_n(x)/Q_m(x)$, where the numerator and denominator are both polynomial in form. This type of function captures various physical behavior phenomena one often encounters. For example, threshold-type behavior, i.e., a situation where a variable x has little or no effect on the output until x crosses a "threshold" value, at which point the output jumps by a considerable amount.

Significance to the M&S Field: Enables the efficient computation of some extremely complex quantities in large scale systems, and enables obtaining virtually accurate, closed-form formulas for these quantities.

Degree of Maturity: The technology is well established and ready to use. It has been applied to many problems and yielded results of remarkable accuracy. Theoretical foundations have also been established.

Potential Air Force Application Area(s)/ Benefit to the Air Force: Computationally complex performance analysis of C^3I systems used in Air Force practice.

Major Players/Leaders Doing Research in this Technology Area:

Wei-Bo Gong
Dept of Electrical and Computer Engineering
University of Massachusetts
Amherst MA 01003
Phone: (413) 545-0384
E-mail: gong@ecs.umass.edu

Christos G. Cassandras
Dept of Electrical and Computer Engineering
University of Massachusetts
Amherst MA 01003
Phone: (413) 545-1340
E-mail: cassandras@ecs.umass.edu

Comments: Several technical publications in this area are available.

Enabling Technology #25: Fuzzy Discrete Event Systems M&S

Brief Description of the Technology Area: Fuzzy discrete event modeling and simulation is an extension of discrete event modeling and simulation to the field of fuzzy set theory. A classical discrete event model can be models as a timed state machine, where state transition function, output function, and sojourn time function are based on crisp set theory. A fuzzy discrete event model is an extension of such functions in fuzzy set theory. Thus, simulation of such a fuzzy discrete event model generates a family of state trajectory of the model, each of which has possibility associated with it. Fuzzy discrete event models are useful in modeling discrete event systems with some uncertainty and ambiguity.

Degree of Maturity: Although fuzzy set theory is matured, no attempt has been made to apply the theory to discrete event systems modeling.

Potential Air Force Application Area(s)/Benefit to the Air Force: This technology would provide great benefits to the Air Force in modeling and analysis of faulty behavior of discrete event systems using the fuzzy set theory. It also would be useful in design of fuzzy discrete event controller.

Major Players/Leaders Doing Research in this Technology Area:

Dr Tag Gon Kim
Department of Electrical Engineering
Korea Advanced Institute of Science and Technology
Taejon 305-701, Korea
Phone: +82-42-869-3454
E-mail: tkim@ee.kaist.ac.kr

Enabling Technology #26: Inductive Modeling/Soft Computing

Brief Description of the Technology Area: A fundamental goal of modeling and simulation is to develop methodologies which provide novel capabilities to the modeler/simulationist. Inductive modeling attempts to determine (infer) a system's internal structure (i.e., concrete representation) from data representing its behavior (i.e., abstract representation). Given that data collected from all kinds of systems are abundant (as very large collections of data are available already and much more is becoming available on a daily basis), realizing a comprehensive inductive modeling methodology will be of significant importance to the M&S community at large. Having a useful and well-defined methodology at their disposal, modelers can utilize it to understand and predict a system's inner working from its observed behavior.

Degree of Maturity: Despite a large body of research in inductive modeling, there is little agreement on any recognized inductive modeling paradigm. Several software implementations exist, including one developed based on a well-defined framework for inductive modeling, and implemented in an Artificial Intelligence Truth Maintenance system supporting nonmonotonic reasoning. This type of reasoning is needed to support flexible assertion and retraction of abstractions and assumptions in model building. However, this work has only tackled "toy problems" and it is imperative to apply it to some real application areas. Fundamental research effort is needed to bring about a useful and mature methodology to support a multitude of Air Force present and future activities within the next couple of years.

Potential Air Force Application Area(s)/Benefit to the Air Force: The present and future mission of the Air Force provides real-world problems for applying and validating an inductive modeling framework. Potential applications span all of the M&S activities of interest to Air Force with significant implications for model characterization from behavior and model abstraction techniques. Examples are Advanced Imagery Exploitation, and Defense Automated Warning Systems, as well as many other areas requiring nonmonotonic reasoning about abstraction and assumptions. An inductive modeling technology would help the Air Force address problems where conventional M&S are inadequate due to an abundance of data together with a lack of a well-developed scientific knowledge base/M&S know-how to make sense of it.

Major Players/Leaders Doing Research in this Technology Area:

Hessam S. Sarjoughian (*)
Electrical and Computer Engineering
University of Arizona
Tucson AZ 85721
Phone: (520)-621-6184
E-mail: hessam@ece.arizona.edu

Thomas G. Dietterich (*)
Computer Science Department
Oregon State University
Corvallis, OR 97331
Phone: (541) 737-5559
Fax: (541) 737-3014
E-mail: tgd@cs.orst.edu

George G. Klir
Systems Science and Industrial Engineering
SUNY at Binghamton
Binghamton NY
Phone: (607) 777-6509
E-mail: rocha@Binghamton.edu

Francois E. Cellier
Electrical and Computer Engineering
University of Arizona
Tucson AZ 85721
Phone: (520)-621-6192
E-mail: cellier@ece.arizona.edu

(*) individuals actively pursuing research with implications as discussed above.

Comments: Articles describing inductive modeling from conceptual, practical, and theoretical views are available at http://www-ais.ece.arizona.edu/~hessam or can be requested via e-mail to hessam@ece.arizona.edu. The inductive modeling methodology under investigation has its foundations in Systems Theory and Non-Monotonic Reasoning. It is able to represent a system's behavior using simple set theoretic notation and, at the same time, employs powerful AI-based mechanisms to do nonmonotonic reasoning necessary for inductive modeling. An attractive and useful feature of our methodology is that it is part of the larger framework of Discrete-Event System Specification (DEVS).

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Hessam S. Sarjoughian
Electrical and Computer Engineering
University of Arizona
Tucson AZ 85721
Phone: (520)-621-6184
Fax: (520)-621-3862
E-mail: http://www-ais.ece.arizona.edu/~hessam

Enabling Technology #27: Fuzzy Systems

Brief Description of Technology Area: Mathematical representation of an intermediate degree of truth (fuzzy logic) or intermediate degree of set membership (fuzzy sets) in a nonprobabilistic way which allows for the construction of intelligent systems through linguistic computation, where system states and propositions are represented by linguistic expressions, and models constructed by a variety of methods for rule construction. There are many application areas, especially in control theory, decision support, and pattern matching. It provides advantages of classical non-linear control, for example, in its smoothness, speed, and low computational and development cost.

Degree of Maturity: Many successful commercial applications.

Potential Air Force Application Area(s)/Benefit to the Air Force: Many, including those mentioned above, and model abstraction and qualitative modeling.

Major Players/Leaders Doing Research in this Technology Area: Many, many. See:

http://gwis2.circ.gwu.edu/~joslyn/work.html#fuzzygroup
http://gwis2.circ.gwu.edu/~joslyn/work.html#fuzzypeop
http://ssie.binghamton.edu/cis.html

Comments: Fuzzy systems are an established area of both research and applications, where Japanese and European efforts are in advance of the US.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Cliff Joslyn
NRC Research Associate
NASA Goddard Space Flight Center
Greenbelt MD 20771
Phone: (301) 286-5773
E-mail: joslyn@kong.gsfc.nasa.gov
WWW: http://gwis2.circ.gwu.edu/~joslyn

Enabling Technology #28: General Information Theory (GIT)

Brief Description of the Technology Area: A collection of mathematical theories for the representation of uncertainty and information in systems in manners which generalize from probability theory. Classical probability theory is retained as a special case. The most prominent component of GIT by far is fuzzy systems (see above). Other promising areas are: Random set (RS) theory and Dempster-Shafer (DS) evidence theory--formally equivalent, representing set-valued random variables and interval-valued probability statements respectively.

Possibility theory: An extreme case of RS and DS, provides a formal analog to probability theory based on concepts of coherence and capacity in the context of GIT. For example, possibilistic Monte-Carlo methods and possibilistic Bayesian networks are defined. Possibilistic methods generalize both interval analysis and nondeterministic process theory.

Rough sets: Modeling of imprecision by nested inner and outer approximations. Formally related to possibility theory. GIT methods are useful or necessary where the mathematical conditions necessary for the applicability of classical probability theory (large sample sizes, decomposable universes of discourse) do not hold. These are key methods for qualitative modeling efforts and are all essentially cases of model abstractions.

Degree of Maturity: Still under development. Initial applications of possibility theory are being brought forward.

Potential Air Force Application Area(s)/Benefit to the Air Force: Many, including those mentioned above, and especially model abstraction and qualitative modeling.

Major Players/Leaders Doing Research in this Technology Area:

Cliff Joslyn at http://gwis2.circ.gwu.edu/~joslyn and
Prof George Klir at http://ssie.binghamton.edu/people/klir.html

Comments: These are promising new areas for qualitative modeling and model abstraction, but still require substantial development.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Cliff Joslyn
NRC Research Associate, Cybernetician at Large
Mail Code 522.3, NASA Goddard Space Flight Center
Greenbelt MD 20771
Phone: (301) 286-5773
E-mail: joslyn@kong.gsfc.nasa.gov
WWW: http://gwis2.circ.gwu.edu/~joslyn

Enabling Technology #29: Fuzzy Modeling

Brief Description of the Technology Area: The model is described in terms of concepts not internal workings. It is a black box that gives the proper input/output relationships without achieving those relationships by mathematical emulation of physical reality. The advantages are simplicity and speed. These models have no trouble in real time on small computers.

Degree of Maturitv: The Japanese commercial users of fuzzy control are the experts. Americans are catching up in control and modeling. No fielded military use is known, but no barrier to it is obvious.

Potential Air Force Application Area(s)/Benefit to the Air Force: The generic benefits are (a) fast modeling, (b) fast computation on small computers, and (c) flexible adjustments/adaptation. All of these should be attractive to the AF.

Major Players/Leaders Doing Research in This Technology Area

J. Caulfield	AAMU	caulfield@caos.aamu.edu
J. Ludman	Northeast Photosciences	71053.3526@compuserve.com
B. Kosko	University of So. California	kosko@sipi.usc.edu

Comments: Prof Witld Pedrycz (University of Manitoba) has just written a lovely overview of fuzzy models in Information Sciences 90, 231-280 (1996).

Prof J. Caulfield's approach relates to his paper on "Fuzzy Metrology" which should appear in the June issue of IEEE Trans. on Fuzzy Logic.

Prof B. Kosko has published an overview in his popular book Fuzzy Thinking. This book is a good introduction to fuzzy logic.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

H. John Caulfield
University Eminent Scholar
Department of Physics
Post Office Box 1268
Alabama A&M University
Normal, AL 35762
Phone: (205) 851-5870
E-mail: caulfield@caos.aamu.edu

Enabling Technology #30: Model Simplification through Formalism Transformation

Brief Description of the Technology Area:

DEVS Representation of Continuous Systems: Continuous systems are traditionally modeled with differential equation models. However, recent research has suggested strongly that discrete event models (DEVS) may provide advantages for simulating continuous as well as hybrid (continuous discrete event) systems. Several approaches exist for faithfully mapping differential equation systems into DEVS models: analytic expression of transitions, application of algebraic solvers, fuzzy representation, etc.

Markov Representation of DEVS Models: A discrete event model, specified by DEVS formalism, which meets conditions has been shown to be equivalent to a Markovian process in steady state. When analytic solutions are available for such processes, they can be solved in much less time than simulation requires. Markov-lumped models can also replace their base model counterparts within the original simulation model leading to more efficient simulation.

Degree of Maturity: Analytic expression of transitions has been shown to provide some 100-1,000 speedup over conventional time-stepped numerical integration. However, in many situations, analytic (local) solution may not be possible. Therefore further research is needed to test general methods that do not rely on analytic solutions.

Potential Air Force Application Area(s)/Benefit to the Air Force: Simulations including both continuous and discrete event model components are very common in AF applications. For example, airplane motion is described with differential equations while decisions of an intelligent autopilot are discrete. In such simulations, the speedups obtainable with a complete DEVS representation, with or without further Markov reduction, would enable simulations to be conducted that are currently not feasible. For example, it would be possible to simulate terrain models using digital elevation data from geographic information systems representing large areas in high enough resolution for realistic tests of sensor systems.

Major Players/Leaders Doing Research in this Technology Area:

Bernard Zeigler

Dr Tag Gon Kim
Department of Electrical Engineering
Korea Advanced Institute of Science and Technology
Taejon 305-701, Korea
Phone: +82-42-869-3454
E-mail: tkim@ee.kaist.ac.kr

Ghi Vansteenkiste
University of Ghent, Belgium

Comments: Y. Moon, B.P. Zeigler, G.L. Ball, & D.P. Guertin, DEVS Representation of Spatially Distributed Systems: Validity, Complexity Reduction, Proceedings of the 6th AI, Simulation and Planning in High Autonomy Systems, San Diego, CA, March 1996.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Bernard Zeigler
Electrical and Computer Engineering
University of Arizona
Tucson,AZ 85721
Phone: (520)-621-6184
Fax: (520)-621-3862
E-mail: zeigler@ece.arizona.edu

Enabling Technology #31: Parallel Simulation; The Use of Parallel and Distributed Platforms to Execute Discrete and Continuous Simulations

Brief Description of the Technology Area: There are a variety of activities in parallel and distributed simulation that will have a large effect on the way simulation is conducted. Parallel simulation allows one to execute a single sample path of a simulation using multiple computers. The object is to exploit large distributed memory (for large simulation models), to accelerate simulation execution speed (for time-critical or (machine/man-in-the loop simulation), and to integrate separately developed serial simulators to cooperate in a parallel fashion without significant alteration to those simulators or models that run on them. We have shown the viability of the approach by demonstrating real speedups of over 250 on 256 processors on some complex, realistic models of communication networks. Another activity is model development for very large distributed models. Demands of parallel simulation encourage certain types of modeling constructs, as do the software engineering demands of developing large-scale models, by distributed organizations. As demands for larger and integrated simulations grow, demands for processing power and modeling ability must grow.

Degree of Maturity: Basic interprocessor synchronization methods are mature. Leaders in the field are active in applying this technology to real-world problems such as large-scale simulations of communication and computer systems. The technology is ripe for application to other large-scale problems, such as transportation simulation, war-gaming, and air traffic control.

Potential Air Force Application Area(s)/Benefit to the Air Force: The technology is well suited for all Air Force simulations that involve many objects in a large domain.

Major Players/Leaders Doing Research in this Technology Area:

David Nicol, Dept of Computer Science, Dartmouth College
Hanover NH 03755
E-mail: nicol@cs.dartmouth.edu

Richard Fujimoto, School of Computing, Georgia Tech
Atlanta GA 30332
E-mail: fujimoto@cc.gatech.edu

Rajive Bagrodia, Dept of Computer Science, UCLA
Los Angles, CA
E-mail: bagrodia@cs.ucla.edu

Comments: Nicol and Fujimoto have a now two year-old paper on the state of the art and open problems, available on request. Nicol has a variety of papers on results of simulating large-scale communications and computer systems, and on integrating serial simulators without modification. All are readily available.

Enabling Technology #32: High Performance Parallel Discrete Event Simulation

Brief Description of the Technology Area: Mapping large-scale discrete event models on massively parallel architectures requires the support of higher level of abstraction in parallel simulation environments. We employed parallel container classes to encapsulate the internode communication mechanism providing a user with a higher level of control. Mapping of DEVS models is also supported by its portability across platforms. Large- scale parallel and distributed DEVS simulation environments demonstrate the capability to address very complex and time-consuming simulation problems while providing a high-level, comfortable interface to the user.

Degree of Maturity: The high-performance simulation environment has been tested on several models including a spatial hydrological watershed and a large cluster of ATM switch models. The simulation can help analyze complex interactions in models of up to 10 million components (e.g., landscape cells or ATM switch elements). Speedups on the order of 200 times have been obtained so that simulations that require several days to run in conventional platforms can be completed in under an hour.

Potential Air Force Application Area(s)/Benefit to the Air Force: There are numerous large simulations that could benefit from this technology. For example, air traffic control and multimedia communication design problems.

Major Players/Leaders doing Research in this Technology Area: Bernard Zeigler and D. H. Kim

References:

B.P. Zeigler, Y. Moon, D.H. Kim, & J.K Kim, (January 1996). DEVS-C++: An Environment for High Performance Simulation. Proceedings of Hawaii International Conference on Systems Science. Maui Hawaii

D. Kim & B.P. Zeigler, (March 1996). Efficient Implementation of Parallel Container Classes for High Performance Simulation, Proceedings of the 6th AI, Simulation and Planning in High Autonomy Systems, San Diego CA.

D. Kim & B.P. Zeigler, (May 1996). High Level Modeling/High Performance Simulation, Proceedings of the Parallel & Distributed Simulation. Philadelphia PA.

Name, Address, Phone Number, and E-mail:

Doohwan Kim and Bernard Zeigler, Dept of Electrical and Computer Engineering
University of Arizona
Tucson AZ 85721
Phone: (520) 621-6184
Email: dhkim@ece.arizona.edu
zeigler@ece.arizona.edu

Enabling Technology #33: Concurrent Simulation

Brief Description of the Technology Area: Simulation is typically used to address "what-if" questions: To answer N such questions, one needs to repeat $(N + 1)$ simulations, one run for the original model and N additional runs for each "what-if." This is excruciatingly slow, if at all feasible, for most complex systems of interest. Concurrent simulation enables the process of obtaining answers to all N "what-if" questions from a single simulation. This is accomplished by intelligently processing the simulation data in a nonintrusive manner. Thus, at the end of one run, all answers to the desired "what-if" questions may be concurrently obtained at the expense of minimal overhead.

Significance to the M&S Field: (1) Orders of magnitude in speedup for otherwise impossible to obtain "what-if" questions; (2) enables potential real-time use of simulation, so far considered a slow, off-line tool limited to long-term design and planning issues--not real-time decision making; and (3) enables use of sophisticated optimization techniques for very complex systems.

Degree of Maturity: Concurrent simulation has been successfully applied to several Air Force programs, including demonstrations of prototypes. There is, however, a need for: generating universal concurrent simulation tools applicable to all existing simulation environments, creating proper software to enable its application by users with minimal expertise, and investigating use of parallel computing as a natural way to further enhance the concurrent aspect of this technology.

Potential Air Force Application Area(s)/ Benefit to the Air Force: This technology may revolutionize decision-making activities and projects performed throughout the Air Force at every phase of virtual prototyping, system design, development, evaluation, testing, and operation. It may transform simulation software into interactive, real-time decision support tools in battle management, logistics, and any resource allocation application area.

Major Players/Leaders Doing Research in this Technology Area:

Christos G. Cassandras
Dept of Electrical and Computer Engineering
University of Massachusetts
Amherst MA 01003
Phone: (413) 545-1340
E-mail: cassandras@ecs.umass.edu

Y.C. Ho
Division of Applied Science
Harvard University
Cambridge MA 02138
Phone: (617) 495-3992
E-mail: ho@paone.harvard.edu

Wei-Bo Gong
Dept of Electrical and Computer Engineering
University of Massachusetts
Amherst, MA 01003
Phone: (413) 545-0384
E-mail: gong@ecs.umass.edu

Comments: Concurrent simulation technology emerged from extensive research in the fields of systems engineering, operations research, and computer science over the 1980s. It is based on research output from areas such as Discrete Event System Theory, Perturbation Analysis, and Queuing Theory. As a general rule, the greater the level of uncertainty and need for statistical tools, the greater the benefit of concurrent simulation technology. It has been applied to such technological settings as manufacturing and communication networks.

A large number of journal articles, conference papers, and technical reports have been published in this area. This work is further described in Rome Lab's Modeling and Simulation WWW site (http://www-ir.rl.af.mil/IR/IRA/IRAE/Efforts).

See also WWW site http://www.ecs.umass.edu/ece/labs/codes.html, which includes an extensive publication list.

Name, Address, Phone Number, and E-mail:

Christos G. Cassandras
Same as above

Wei-Bo Gong
Same as above

Enabling Technology #34: Quantification of Fidelity. Relating simulator fidelity to counterpart operational system usage.

Brief Description of the Technology Area: Quantifying simulator fidelity in terms useful to developers and users is difficult and time consuming. In systems with high degrees of cognitive and psychomotor activity, this quantification is even more difficult. The Institute for Simulation and Training has developed a technique where pilot stick activity is captured and processed using Fast Fourier Transforms (FFT). The FFT is a measure of psychomotor activity with an implied remainder of activity devoted to cognitive processes. A "fingerprint" of an individual operator or an expert can be captured. Task loading and, indirectly, fidelity can be assessed by analyzing the FFT against the expert baseline or the individual fingerprint.

Degree of Maturity: Limited tests have been performed with Air Force pilots from the 56th Tactical Fighter Wing. Initial results appeared promising. This technology needs additional maturation by testing statistically significant groups of operators, a variety of platforms, and a variety of tasks.

Potential Air Force Application Area(s)/Benefit to the Air Force: Application to Air Force needs are particularly relevant to single-pilot aircraft (high cognitive and psychomotor environment). Initial results were provided to the F-22 contractor. Continuing this work will help define simulator fidelity requirements for specified tasks and serve as a screening mechanism for new pilots.

Major Players/Leaders Doing Research in this Technology Area: Institute for Simulation and Training, University of Central Florida, Mr Brian Goldiez; Naval Air Test Center, Patuxent River, MD, Dr Richard Dunn; Naval Research Laboratory, Washington, DC, CDR Dennis McBride.

Comments: The initial research was developed to assist in determining why SIMNET-type devices were not acceptable to the aviation community. Initial results using the techniques described above and experienced F-16 pilots indicated improvements were necessary to flight dynamics and visual field of view to support team training.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Mr Brian Goldiez
Institute for Simulation and Training
University of Central Florida
3280 Progress Drive
Orlando FL 32826
Phone: (407) 658-5015
E-Mail: bgoldiez@ist.ucf.edu

Enabling Technology #35: Simulated Environment Interoperability between and among Mixed Fidelity Simulators

Brief Description of the Technology Area: Simulators using DIS or HLA are normally produced by a variety of vendors and interact with each other and computer-generated forces (CGF). All of these simulators need to operate in the same battlespace, but yet have their own independent environmental representation. Techniques have been developed to measure where the differences in the environment become sufficiently different to adversely affect a fair fight. The techniques consist of statistically valid measurement techniques, criteria, and analysis tools for assessing the impact on environmental interoperability.

Degree of Maturity: This technology is prototypical for ground combat and the ground portion of the synthetic battlespace. It has been used and refined for the past three Interservice/Industry Training Systems and Education Conference (I/ITSEC) interoperability demonstrations and for the HLA platform prototype federation.

Potential Air Force Application Area(s)/Benefit to the Air Force: This tool could be expanded to include air-to-ground interactions as well as extensions into an air-only environment. For example, weather and atmospheric effects could be included in this methodology, all contributing to the joint synthetic battlespace.

Major Players/Leaders Doing Research in this Technology Area: The Institute for Simulation and Training, University of Central Florida, Mr Brian Goldiez and Dr Guy Schiavone.

Comments: The techniques which have been prototyped have a strong reliance on using computer-generated forces as "subjects" and having subject-matter experts observe the CGF behavior. The methodology has been developed and documented under STRICOM and DMSO sponsorship. We believe this technology can also be extended to study battlespace interoperability of different types of simulations (e.g., NASM and JSIMS) and between varying levels of simulator granularity (e.g., Virtual and Constructive).

Name, Address,Phone Number, and E-mail:

Brian Goldiez and Guy Schiavone
Institute for Simulation and Training
University of Central Florida
3280 Progress Drive
Orlando FL 32826
Phone: (407) 658-5000
E-mail: bgoldiez@ist.ucf.edu or guy@ist.ucf.edu

Enabling Technology #36: Physics-Based Sensor Models

Brief Description of the Technology Area: The area of physics-based sensor models involves the direct application of physical principles to the simulation of microwave, millimeter (MMW), and infrared (IR) sensors in the calculation of electromagnetic (EM) scattering for cases where resonance-region phenomena and coherent effects are important. This differs in many respects from current approaches which rely on heuristic or statistical models to calculate EM scattering, especially from backgrounds. The advantage of the physics-based approach is that it is capable of providing consistent returns from targets and backgrounds across the entire EM spectrum.

Degree of Maturity: Parallel or distributed approaches may presently allow for direct real-time calculation of EM scattering for relatively simple targets and backgrounds, however, further work is needed to determine the extent and usefulness of current capabilities. Limitations are encountered both in processing power and total main memory capacity, and as these continue to increase, so does the feasibility and potential usefulness of the physics-based approach.

Potential Air Force Application Area(s)/Benefit to the Air Force: The implementation of high-fidelity, physics-based sensor simulators will improve training efficacy and should prove useful in the design of new weapons systems.

Major Players/Leaders Doing Research in this Technology Area: The implementation of real-time, physics-based sensor models has not yet been attempted, to my knowledge. McDonnell Douglas and Lockheed Martin are two major players in the area of radar system simulation devices.

Comments: The importance of resonance-region phenomena in IR imaging has been discussed in a series of papers authored or co-authored by N. S. Kopeika. Obviously, at lower frequencies, resonance-region phenomena and coherent effects become increasingly important.

Name, Address, Phone Number, and E-mail:

Guy A. Schiavone
Institute for Simulation and Training
University of Central Florida
3280 Progress Drive
Orlando FL 32826
Phone: (407) 658-5501
E-mail: guy@vsl.ist.ucf.edu

Enabling Technology #37: Seamless Universal Voice Interchange System (SUVIS)

Brief Description of the Technology Area: This technology provides for spoken voice interchange in virtual simulation. It also has English-like language for specification and execution of Computer-Generated Force (CGF) behaviors. Distributed Interactive Simulation (DIS) has effectively addressed human-to-human communications, however, the DIS world includes other kinds of communication, such as those which can be produced by constructive models and virtual CGFs. With more sophisticated use of CGF systems in intelligence gathering and dissemination models, there will arise the requirement for radio/voice communication between the different kinds of players (including human-CGF). If this "interspecies" communication cannot be made transparent to the players, then the simulations will lack a crucial capability and the "seams" will remain and intrude.

IST's proposed approach involves hardware and software tools (speech recognition, voice synthesis, dictionaries, et al.) to convert simulated radio traffic between all of the involved formats (live audio, digitized speech, ASCII text, and dictionary indices). It uses a symbolic, English-like, interpreted language (ILLISH) as an intermediate form for communication with computer-generated entities and to allow nonprogrammer, subject-matter experts (SMEs) to specify behavior of CGF entities.

Degree of Maturity: SUVIS is in the conceptual development stage. White papers and research proposals from IST have had positive reactions from the modeling and simulation community.

Potential Air Force Application Area(s)/Benefit to the Air Force: This technology would allow the Air Force to create voice interactive CGFs. It would permit non-programmers who are SMEs to define and modify behavior as required. It would satisfy a long-standing requirement for voice radio applications in virtual and constructive simulations. The technology also has voice recognition/synthesis applications in maintenance, logistics, operations, intelligence, etc.

Major Players/Leaders Doing Research in this Technology Area: Institute for Simulation and Training, University of Central Florida, Mr Scott Smith.

Comments: White papers, proposals, and technical papers (ITEA and DIS Workshops) are available.

Name, Address, Phone Nnumber, and E-mail:

Mr Scott Smith
Institute for Simulation and Training, University of Central Florida
3280 Progress Drive
Orlando FL 32826
Phone: (407) 658-5531
E-mail: ssmith@ist.ucf.edu

Enabling Technology #38: Computer-Generated Forces

Brief Description of the Technology Area: Computer-generated force (CGF) systems populate a simulated battlefield with entities not directly controlled by a human in a simulator. In the training domain, trainees need realistic opponents to fight against and realistic compatriots to fight with. Using humans to fill all the roles in a training exercise is generally an expensive approach. CGF systems are a relatively inexpensive method for increasing the realism of the simulated battlefield by providing interactive, adaptive entities that challenge and support the trainee.

Degree of Maturity: This technology is mature enough for application in AF programs within one to two years.

Potential Air Force Application Area(s)/Benefit to the Air Force: In addition to the benefits of providing challenging opponents in the training domain, CGF systems are applicable in analytic studies. Virtual Test and Evaluation (VTE) studies are possible to evaluate new systems throughout the design process. VTE allows examination of design concepts in simulated combat without the development of physical prototypes. Thus information about design choices can be obtained early during design to focus detailed analysis on promising alternatives.

Major Players/Leaders Doing Research in this Technology Area: Institute for Simulation and Training, University of Central Florida, Mr Clark R. Karr; SAIC, Mr Anthony Courtrache; Sagacitech, Mr Joshua Smith; and Lockheed Martin.

Name, Address, Phone Number, and E-mail:

Clark R. Karr
Institute for Simulation and Training
University of Central Florida
3280 Progress Drive
Orlando FL 32826
Phone: (407) 658-5015
E-mail: ckarr@ist.ucf.edu

Enabling Technology #39: Three-Dimensional, Stereoscopic, Pseudo-holographic, Real-Time Display of Computer-Generated Imagery, recently becoming known as "Virtual Modeling." The system is called "Mirage."

Brief Description of the Technology Area: Mirage provides an image of three-dimensional (3D) data which appears as a scale model resting on a tabletop before the viewer. The viewer may walk around the table permitting a view of the scene from any angle.

Degree of Maturity: Mirage is a proven system. It has been demonstrated at IST, Naval Research Lab, Stanford, and will be shown at the Pentagon in September. It will also be delivered to the U.S. Army Strategic Space Defense Command in December. Commercial hardware capable of displaying this imagery is available from FakeSpace, Inc., however, they do not deliver software. All applications to date are demonstrations with full development awaiting customer demand.

Potential Air Force Application Area(s)/Benefit to the Air Force: The Air Force could use the potential of this system in many areas. EW displays, showing the layout of both friendly and enemy EW systems, would enable more effective targeting of systems that were the most threat. JSTARS output could be displayed with Mirage showing the terrain as well as permanent structures and mobile targets. The status of logistics and ground personnel could be plotted geographically with the potential of showing the weak points for possible terrorist activity.

Major Players/Leaders Doing Research in this Technology Area: Institute for Simulation and Training, University of Central Florida, Mr Scott Smith and Dr Thomas Clarke.

Comments: White papers are available.

Name, Address, Phone Number, and E-mail:

Scott Smith
Institute for Simulation and Training
University of Central Florida
3280 Progress Drive
Orlando FL 32826
Phone: (407) 658-5531
E-mail: ssmith@ist.ucf.edu

Enabling Technology #40: Multi-Resolution Simulation

Brief Description of the Technology Area: Combat Results Correlation Error (CRCE): Multi-Resolution Simulations (MRSs) are those which simulate the battlefield at different levels of resolution (e.g., at vehicle and unit levels). Typically, separate simulations deal with different levels of resolution; for example, an aggregate simulation may simulate military units down to the battalion while an entity simulation would simulate the individual platforms within a military unit.

Interoperating simulations at different levels of resolution provide the scope and power of each simulation but can result in correlation errors during combat. CRCEs are detectable when events in one simulation do not match those in another simulation. For example, a battle that is resolved at one level of resolution has different results from the same battle resolved at a different level of resolution. These CRCEs are a product of discrepancies between the simulations in terrain representation, simulation time flow, performance parameters, behavioral responses, and event resolution.

The intent with MRS is to simulate the complete battlespace (or a major part of it) by simulating portions at different levels of resolution. For example, a theater perspective might be simulated at a low resolution while close air support or airfield defense would be simulated at high resolution. Another example is in a study of a particular weapon system in which only engagements involving the weapon system would be simulated at a high resolution. Unfortunately, CRCEs limit the usefulness of the MRS approach. Mis-correlation of results between simulations call into question the MRS system's results.

Degree of Maturity: The technology is immature. MRS in general and CRCE in particular need research to isolate and quantify the relevant factors and to develop strategies to mitigate or solve the problem.

Potential Air Force Application Area(s)/Benefit to the Air Force: Research into CRCE will allow the AF to leverage its investment in simulations by allowing the creation of MRS simulations from existing simulations.

Major Players/Leaders Doing Research in this Technology Area: Institute for Simulation and Training, University of Central Florida, Mr Clark R. Karr and Mr Robert Franceschini.

Name, Address, Phone Number, and E-mail:

Clark R. Karr
Institute for Simulation and Training
University of Central Florida
3280 Progress Drive
Orlando FL 32826
Phone: (407) 658-5052
E-mail: ckarr@ist.ucf.edu

Enabling Technology #41: Embedded Training

Brief Description of the Technology Area: Embedded training is a very broad term that covers essentially the live aspects of modeling and simulation. The real value of embedded training is that it is embedded in the operational systems and therefore is always available to the service member, which is especially valuable during deployments. Embedded training has the ability for combat systems to be used as an excellent tool for unit and individual training and greatly reduce training transfer issues.

Degree of Maturity: For many applications, where software and visual displays are key (such as in C2 or electronic troubleshooting), embedded training applications are mature enough to be used today. For other applications, the types of training tasks or the equipment involved are the determining factors. Embedded training works best for primarily intellectual skills and procedural tasks that include rule-using behaviors. Tasks that are heavily in the psychomotor domain or that are involved with heavily mechanical systems are less applicable at the current level of maturity. Future applications will be a function of research and the growing technology movement to more reliance on software-driven systems and "glass cockpits."

Potential Air Force Application Area(s)/Benefit to the Air Force: The ultimate advantage and goal of embedded training would be the reduction of part-task training and training systems that intend to replicate "real" instruments and workstations. Using constructive models to drive training objectives, actual C2 equipment, such as Theater Battle Management Core Systems (TBMCS) and JFACC Situational Awareness System (JSAS) could be used to train joint personnel in combat skills in a training environment, but on actual equipment. In addition, dual-use software and infrastructure would result in major savings and reduced maintenance.

Major Players/Leaders Doing Research in this Technology Area: Institute for Simulation and Training, University of Central Florida; Air Force Research Laboratory; Army Research Institute; University of Massachusetts; University of North Carolina; US Army, (STRICOM); Loral; SAIC; DARPA; and Rome Labs.

Comments: Two major issues that must be considered for embedded training applications are applicability of types of learning (i.e., considering embedded training as a medium) and implications on mission requirements of equipment (do not embed training where there is no natural visual system or display for representation of stimuli).

Name, Address, Phone Number, and E-mail:

Ronald W. Tarr
Institute for Simulation and Training, University of Central Florida
3280 Progress Drive
Orlando FL 32826
Phone: (407) 658-5080
E-mail: rtarr@ist.ucf.edu

Enabling Technology #42: After-Action Review and Unit Performance Measurement

Brief Description of the Technology Area: Provides tools to assist in preparing unit performance summaries necessary to provide units with feedback during After-Action Reviews (AARs). These tools allow for the real-time, continuous assessment of desired measures of merit to be identified and evaluated. Many simulations and wargames do not have access to this dynamic reporting and, as a result, lose valuable training feedback. These tools contain a number of AAR programs collectively called the Unit Performance Assessment System (UPAS). Timeliness in preparing feedback is critical as delay decreases the value to the participants who are fighting in a dynamic environment.

Degree of Maturity: The AAR tools included in UPAS as a complete package have been used at Ft Knox and various other sites in the US and overseas locations. This system proved to be a very useful training aid during simulation exercises. The technology is ready to be employed in any simulation environment.

Potential Air Force Application Area(s)/Benefit to the Air Force: This technology is available to be used in a wide variety of joint or AF wargaming environments. It is available for use in constructive, virtual, live, or combination simulations, as required. It provides immediate feedback to the training audience, significantly improving the quality of the training provided and improving the quality of feedback to the trainees.

Major Players/Leaders Doing Research in this Technology Area: Institute for Simulation and Training, University of Central Florida, Mr Seng Tan; and Army Research Institute, Dr Larry Meliza and Dr Dave Bessimer.

Comments: It is recognized prompt and timely feedback to exercise participants is paramount to success and usefulness of AAR tools. While AAR tools have proved to be useful in general, it is highly desirable to decrease the amount of time needed to prepare various exercise analysis reports and graphs prior to briefing exercise participants. Currently, data collection and data conversion are not overlapped. Raw data conversion to relational database format is an intermediate step prior to generating final reports and graphs and is currently done in sequence after data collection. By overlapping data collection and data conversion, the amount of time required to prepare final reports with good analysis will be drastically reduced. More research effort is needed to overlap data collection and conversion.

Reference: Application of SIMNET Unit Performance Assessment System to After- Action Reviews by Larry Meliza, ARI, and Seng Tan, IST.

Name, Address, Phone Number, and E-mail:

Mr Seng Tan, Institute for Simulation and Training, University of Central Florida
3280 Progress Drive
Orlando FL 32826
Phone: (407) 658-5534 E-mail: stan@ist.ucf.edu

Enabling Technology #43: Calendaring via the World Wide Web (WWW)

Brief Description of the Technology Area: Allows coordination of events, such as exercises, meetings, conferences, etc. by collecting and storing items in a "calendar database" accessible via the WWW. This database then can be used to coordinate events for a single base, several bases, or any combination. The format provides one place to go to find a schedule of events. The calendar automatically takes inputs from other WWW calendar sites and integrates them into the all-inclusive database that gives a view of the consolidated calendar. Other agencies have developed application software to schedule activities on a local area network, but the Institute for Simulation and Training (IST) is the only one to integrate that scheduling into the WWW to display multiple views.

Degree of Maturity: The Information Technology Service Center of IST has developed the application and currently services over 30 calendars. Ft Leavenworth, Kansas, has also recently decided to use the software to coordinate all fort activities.

Potential Air Force Application Area(s)/Benefit to the Air Force: Reduces staffing and coordination time. Administration of the calendar is performed via the WWW, so anyone, anywhere, with management access, can manage it. Depending on security preferences set by the manager, anyone with desired access can view the calendar.

Major Players/Leaders Doing Research in this Technology Area: IST, University of Central Florida, Ms Tammie McClellan and Mr Robert Reed; and Netscape.

Comments: Netscape has recognized the need for calendars and is currently in the development stage of creating their own software.

Name, Address, Phone Number, and E-mail:

Ms Tammie McClellan
Institute for Simulation and Training
University of Central Florida
3280 Progress Drive
Orlando FL 32826
Phone: (407) 658-5000
E-mail: tmcclell@ist.ucf.edu

Enabling Technology #44: Document Collaboration via the World Wide Web (WWW)

Brief Description of the Technology Area: Allows geographically dispersed teams to work collectively on documents (standards, policy, proposals, etc.) using the WWW as the primary communication medium. Unlimited team size, full audit of all comments, and designated decision makers are all benefits of this approach. Additionally, there is no document "downloading-uploading," and all comments are visible to everyone eliminating many potential errors.

Degree of Maturity: The concept is being introduced now through commercial software but it is very expensive--currently several hundred dollars per user. WWW and browser technology is quite mature.

Potential Air Force Application Area(s)/Benefit to the Air Force: The Air Force could substantially reduce the cost of document development across widely disparate teams. Staffing time, as well as coordination and production time, could be greatly reduced. It also provides the opportunity to involve anyone, anywhere--quickly, easily, and inexpensively.

Major Players/Leaders Doing Research in this Technology Area: Institute for Simulation and Training, University of Central Florida, Mr Robert Reed; LOTUS, workgroup collaboration tools; MicroSoft; Netscape; Digital Equipment; and others.

Comments: At the moment, other research focuses on proprietary formats and high cost (due to licensing). Using the WWW eliminates proprietary formats and virtually wipes out all costs for any number of participants.

Name, Address, Phone Number, and E-mail:

Mr Robert Reed
Institute for Simulation and Training
University of Central Florida
3280 Progress Drive
Orlando FL 32826
Phone: (407) 658-5501
E-mail: rreed@ist.ucf.edu

Enabling Technology #45: Environment Representation in Advanced Distributed Simulation Entity-Level, Force-on-Force Simulations

Brief Description of Technology Area: Real-time simulation of environmental phenomena in virtual world simulations and their effects on sensor effectiveness and vehicular mobility. Specific phenomena modeled are:

- atmospheric transmittance due to weather effects, such as fog, haze, rain, and snow; transmission through clouds is now in development
- natural illumination as a function of time of day and year, and global position;
- weather effects on target contrast;
- local obscuration effects (including wind effects) due to battlefield smoke (burning vehicles, smoke munitions, etc.), artillery dust and vehicular dust;
- signal smoke and flares;
- illumination flares;
- weather effects on terrain (in development), and
- ocean wave and sea state (in development).

Degree of Maturity: All of the above functionality is currently integrated in ModSAF 2.1 and available through the DMSTIAC (at US Army STRICOM). It is planned for incorporation in the Synthetic Theater of War (STOW) OpenSAF, and for demonstration as part of STOW ACTD. More work needs to be done in two areas: (1) extending environmental effects to various sensor domains (IR, radar, acoustic)--most work has concentrated on visual sensors, and (2) development of environment-related interactions with Synthetic Forces.

Potential Air Force Application Area(s)/Benefit to the Air Force: The technology has direct applicability to command-level Joint or Service training simulation environments, such as JSIMS or NASM.

Major Players/Leaders Doing Research in this Technology Area:

Mr Richard Schaffer
Lockheed Martin
Advanced Distributed Simulation
50 Moulton Street
Cambridge MA 02138

Mr George Lukes, PM Synthetic Environments
Defense Advanced Research Projects Agency
Arlington VA

Mr Jeff Turner, PM Synthetic Environments
US Army Topographic Engineering Center
Ft Belvior, VA

Enabling Technology #46: Exercise Management for Distributed Simulations

Brief Description of the Technology Area: The Lockheed-Martin ExMan (Exercise Manager) is a tool for setting up, running/monitoring and reviewing distributed exercises made up of DIS-compliant simulations. It replaces the current manual approach to organizing and setting up exercises with a computer-mediated process that reduces the time and human effort required. The ExMan relies on an HTML forms-based approach for sharing information between the simulator and the human exercise controller that follows the current High Level Architecture (HLA) for forming federations of players. The ExMan currently is also HLA-compliant and is part of the Engineering Proto-Federation.

Degree of Maturity: The ExMan Tool has been developed over the past three years at the Lockheed Martin Palo Alto Software Technology Center and runs on a standard Unix workstation. It is coded in C++. It has been used to coordinate exercise demonstrations at Lockheed-Martin facilities in Palo Alto and Sunnyvale, CA; at Lockheed-Martin, Fort Worth and Sanders, as well as at I/ITSEC 93 and 94 and at SuperComputing 94 and 95.

Potential Air Force Application Area(s)/Benefit to the Air Force: ExMan is particularly appropriate for simulation of AF exercises including AF mission planning and laydown (since route planning and similar set up functions are done on an aircraft-by-aircraft basis) and has been integrated with Sanders. Moreover, we have simulated space sensor platforms for analyses of future air missions involving close coordination with national assets.

Major Players/Leaders Doing Research in this Technology Area: In addition to us, the DIS community has set up a large number of subcommittees to develop standards in this area.

Comments: For more information on our M&S capability, see a WWW description at: http://badger.parl.com/modsim/

Name, Address, Phone Number, and E-mail:

Dr David Milgram
Lockheed Martin Advanced Technology Center
M/S: 9610/255
3251 Hanover St.
Palo Alto CA 94304
Phone: 415-424-2277
Fax: 415-354-5235
E-mail: milgram@stc.lockheed.com

Enabling Technology #47: Agent-Based Simulations of Complex and Complex Adaptive Systems

Brief Description of the Technology Area: SFI is developing several approaches to simulating the evolution of systems consisting of multiple-interacting, adapting (learning) agents. These simulations are applicable to social, physical, biological, and mechanical systems of agents. The purpose of these simulations is to investigate the emergence of behaviors and structures in complex systems and to provide a means for replicable scientific research in which simulation occupies the role normally played by experimentation.

Degree of Maturity: The Swarm Simulation System is in a final beta version and available for downloading from http://www.santafe.edu/projects/swarm/release. Over the next year it will be augmented by contributions from users to its basic libraries. There are currently about 75 users conducting early applications with Swarm.

Potential Air Force Application Area(s)/Benefit to the Air Force: To date the Navy has shown the strongest interest in Swarm, which is being used to model groups of RPVs (NRL) and communications networks (TI). Swarm was demonstrated to approximately 40 Air Force scientific directors at a meeting in Santa Fe that was convened by the AF Chief Scientist, Ed Feigenbaum. There are other applications not necessarily known to Santa Fe Institute.

Major Players/Leaders Doing Research in this Technology Area:

Mr Roger Burkhart
Deere & Company
Phone: 309-765-4365
E-mail: roger@go.deere.com

Comments: Additional information is available at the Santa Fe Institute web site http://www.santafe.edu.

Name, Address, Phone Number, and E-mail:

Mr Bruce Abell
1399 Hyde Park Road
Santa Fe NM 87501
Phone: (505) 984-8800
E-mail: babell@santafe.edu

Enabling Technology 48: General Object-Oriented Simulation Environment

Brief Description of the Technology Area: The Integrated Model Development Environment (IMDE) is a state-of-the-art, object-oriented simulation development system. It manages the entire life cycle of simulation development and use, from initial object definition, project construction, experiment definition, simulation execution, to results analysis and data reduction. IMDE is completely domain independent and is capable of addressing simulation development in the live, virtual, or constructive simulation areas. The majority of experimentation has been in the domain of constructive simulations. IMDE generates language independent internal models which can be used to generate C++ or ModSIM II language models. IMDE has a number of extension classes in the form of libraries, including graphics, expert system, and script-based planning classes. Additional research is in progress to develop classes for distributed interactive simulation (DIS), parallel simulation, and distributed simulation classes. The latter components will be used in a model to obtain parallelism and distribution and by IMDE to distribute and parallelize multiple simulation experiment runs on available resources. The real power in IMDE is the advanced interface. IMDE creates a drag-and-drop environment, much like visual C++, for simulation. New simulations can be created by dragging together objects of interest. Templates can be used to facilitate classes of simulation models. Modifications for maintenance and alternate simulation requirements can utilize OO class substitution, polymorphism, and dynamic construction to allow fast construction and modification. The goal is create a library of simulation entities that facilitate rapid simulation development.

Degree of Maturity: IMDE has been under development for almost four years, with the last year primarily for testing and development of extension classes. The system is scheduled for transfer later this year, where it should begin a final 6.4 effort to make it robust and complete. The 6.4 effort is expected to take two years to complete under a moderate development effort. The current laboratory version has been used in several studies and test models, which have shown both the value of the technology as well as identified many of the bugs and issues, many of which have been resolved.

Potential Air Force Application Areas/Benefit to the Air Force: IMDE is a general, domain-independent system. As such, it can be applied to almost any Air Force problem domain. The primary domains addressed thus far have been the logistics and command and control domains. Under logistics, manpower and spares models have been considered and replicated in IMDE. IMDE has been shown to have all the features of the current Air Force standard Logistics Composite Model (LCOM) and as such has been voted by that community to be the replacement to the 30-year old current system. The Air Force Management Engineering Agency will be taking possession of the system and will be overseeing the 6.4 development. Under the command and control domain, IMDE has been used as a coarse of action analysis tool during the crisis action planning cycle for the DARPA Joint Task Force Advanced Technology Demonstration (JTF-ATD). It has been demonstrated at the Joint Warfighter Interoperability Demonstration 95 (JWID), and is currently being incorporated into another lab effort to produce a next generation wing assessment and information management system.

Major Players/Leaders Doing Research in this Technology Area: Integrated Model Development Environment - Air Force Research Laboratory, Wright-Patterson AFB OH - Capt Todd Carrico (Phone: DSN 785-2606). There is an abundance of technology and research efforts in modeling and simulation, but nothing is directly comparable to IMDE. Other systems like the Joint Modeling and Simulation System (JMASS) have a similar design paradigm, but very different goals and developments.

Comments: The IMDE system is currently available under the Sun Solaris and HP computing environments. As a proof of concept, we are going to perform a primary port to the Windows/NT platform later this summer. Though IMDE technology has had a fantastic reception, in our current environment, obtaining the funding to complete the 6.4 development has been difficult. Currently, AFMEA has been unable to secure all the funds required to complete the development.

AF/XOM awarded the IMDE 6.4 development $100K under the model improvement program (improvement to LCOM by replacing it with IMDE). Additional funding from AF/PE and the MAJCOMs is currently being pursued.

Name, Address, Phone Number, and E-Mail:

Capt Todd M. Carrico or 1Lt John DiPasquale
Air Force Research Laboratory
Wright-Patterson AFB OH 45433
Phone: (513) 255-2606
DSN 785-2606

Enabling Technology 49: Representational Resolution and Fidelity

Brief Description of the Technology Area: The focus of this area is on the representation of simulation entities and their interactions at an appropriate level of resolution and fidelity. The premise is that appropriateness should be determined by the end-use requirements posed on the simulation. The goal of efforts in this area is to provide a representation of entities and their behaviors that is sufficiently detailed to support the intended end use, yet lacks any unnecessary complexities. Avoiding such complexities reduces the developmental and computational requirements associated with the simulation, enables the representational focus to remain end-use motivated, and reduces the false security of "more is better."

One technical approach under study in this area is generally identified by the rubric "aggregation/disaggregation." Aggregation is the process of representing groups of entities rather than individual entities within a simulation. In the realm of military combat simulations, aggregation has long been employed to balance the need to represent a large number of combatants and types of weapon systems, the computational capabilities available, and required execution times. This coarser grain representation of combatants sacrifices detail in exchange for a large scope of simulated combat while the computational requirements remain relatively constant. An obvious result of this increase in representational granularity is the loss of information relating to the individual combatants that comprise the aggregations (units). This results from the aggregation (collapsing) of a large number of characteristics (facets) of individual combatants into a limited number of measures representing the group (unit) at large.

An aggregation/disaggregation scheme (dynamically) changes the representational fidelity/resolution of simulated entities in response to well-defined contextual factors or events. This change is intended to reduce or eliminate loss of information attributed to aggregation while still retaining, where appropriate, benefits associated with aggregation. Several key issues must be addressed in such situations, such as the appropriate transformation from a lower fidelity/resolution representation to a higher fidelity/resolution representation (disaggregation) and vice versa (aggregation). More fundamentally, the issue of critical representational complexity, i.e., how much must be simulated to address the question of interest, is an active area of research here.

Degree of Maturity: The body of work to date has concentrated on increasing our understanding of the technical issues, including the development of several simulation prototypes to support these explorations. Though preliminary results have been encouraging, research in this area is still needed to increase our understanding of the fundamental issues and technical approaches. In addition, we need to mature the fundamental science necessary to understand how to effectively couple requirements with fidelity and resolution choices.

Potential Air Force Application Area(s) / Benefit to the Air Force: The technology area has potentially broad use in all application areas utilizing simulation. The primary benefit of this technology is a fundamental understanding of issues relating to representation in simulation. This understanding, paired with computational approaches such as aggregation/disaggregation,

will enable simulations to effectively represent desired entities and behaviors in a credible manner.

Major Players/Leaders Doing Research in this Technology Area: Not known.

Comments: Several research papers, addressing specific technical issues in this area, are available upon request.

Los Alamos Point of Contact:

Dr Randy Michelsen
Los Alamos National Laboratory
MS F602
Los Alamos NM 87545
Phone: (505) 667-0789
Fax: (505) 665-2017
E-mail: rem@lanl.gov

Enabling Technology 50: High Performance Computing

Brief Description of the Technology Area: High performance computing R&D efforts are focused on providing platforms capable of increasing effective application speeds by several orders of magnitude by the turn of the century. Primary impetus of these efforts is to dramatically increase the nation's predictive modeling and simulation capability to support future growth of science and engineering. This is evidenced within the DoD by increasing reliance on modeling and simulation in areas ranging from future force structure studies to test and evaluation studies of proposed systems. Technical thrusts include development of new computer architectures, high performance networking, high capacity data storage systems, advanced 3D data visualization approaches, distributed computing technologies, and innovative software development/collaboration environments. Architectural approaches include high performance, heterogeneous, distributed computing solutions; massively parallel supercomputers (MPPs); and clusters of shared-memory multiprocessors interconnected with a high-speed, switching network (SMPs). The Department of Energy's Accelerated Strategic Computing Initiative (ASCI) is an example of a large, multidisciplinary program intended to dramatically enhance our predictive M&S capability.

Degree of Maturity: Current high performance computer architectures are capable of executing billions of instructions per second (gigaFLOPS). In the DOT transportation simulation effort, we have successfully used a clustered, message-passing architecture to simulate interactions of millions of vehicles in a single second of real time. In face of relatively rapid improvements in available computational power, many challenges remain in both computer hardware and software domains to produce and effectively harness teraFLOP class architectures. The ambitious goal of initiatives such as ASCI is tens or hundreds of trillions of instructions per second (teraFLOPS) by the end of the century. DOE's Grand Challenge problems such as modeling of global ocean/climate modeling using MPPs will produce upwards of two gigabytes of data per simulated month. Currently, approximately 100 technical staff are engaged in R&D activities in the hardware and software domains. It is anticipated that during the next year, a three teraFLOP SMP cluster will be operational at the Laboratory. Initial implementation efforts will focus on the areas of an application development environment, application execution support, and information assimilation (visualization).

Potential Air Force Application Area(s)/Benefit to the Air Force: Application areas include any in which current computational capabilities limit the ability to represent behaviors or interactions. The primary benefit this technology promises is the computational ability to represent, in an M&S context, the behavior of entities and materials with unprecedented fidelity. In addition, the new architectures promise scalability to a degree previously unattainable. Finally, the combination of high performance data storage systems, high speed networks, and advanced data visualization workstations enables the movement and effective interpretation of the massive quantity of data that will be generated.

Major Players/Leaders Doing Research in this Technology Area: Numerous.

Comments: Additional information regarding the technical efforts discussed above are available upon request.

Los Alamos Point of Contact:

Dr Randy Michelsen
Los Alamos National Laboratory
MS F602
Los Alamos NM 87545
Phone: (505) 667-0789
Fax: (505) 665-2017
E-mail: rem@lanl.gov

Enabling Technology #51: Software Reuse via Composition

Brief Description of the Technology Area: In this approach to software reuse, a simulation is developed by combining software components (objects) to create an executable simulation. Simulation entities (e.g., representations of aggregated military units or weapon platforms) and other required components are selected from appropriate software objects residing in one or more reuse repositories. These software elements are then combined (composed) into a simulation. This composition approach supports high-level architecture precepts being developed by the Defense Modeling and Simulation Office. Potential benefits of this approach to simulation construction are numerous. The object-oriented approach that it is predicated on offers substantial benefits from a software engineering standpoint with benefits accrued in design, implementation, and maintenance phases. In addition, the focus on engineering the components properly places emphasis on representational quality of the simulation entities. This in turn facilitates a component-oriented view of verification and validation. Finally, this "building block" approach enhances the vitality of individual representations since rebuilding or replacing individual components is much more tractable/feasible than replacing a large monolithic simulation.

Degree of Maturity: The body of work to date has concentrated on developing a proof-of-concept simulation composition environment. The basic goal was to demonstrate the concept was technically feasible. Current focus is on demonstrating that users who are not professional software developers can readily compose credible simulations. To date, we have developed a software prototype which provides reuse repositories, a graphically oriented composition interface, and several simplified suites of simulation entities to demonstrate concept feasibility. We are presently developing, under the auspices of the JWARS program, a suite of prototype simulation objects to support several sample analytical use cases in a joint warfare context. These objects, combined with the composition environment, will enable composition, execution, and retention of a credible combat simulation. While concept feasibility has been demonstrated, research must still be focused on assessing its scalability and extensibility. In addition, we are examining coupling of the composition paradigm to requirements posed by the HLA.

Potential Air Force Application Area(s)/Benefit to the Air Force: Application would be any end use requiring simulation development or refinement. Primary benefits promised are ability to effectively reuse simulation entities represented as software objects and (thereby) create simulations tailored to address requirements posed by specific analytical questions. The technology also facilitates definition and development of simulation entities by appropriate service proponents and thus facilitates creation of credible, mutually validated, joint simulations.

Los Alamos Point of Contact:

Dr Randy Michelsen
Los Alamos National Laboratory, MS F602
Los Alamos NM 87545
Phone: (505) 667-0789 Fax: (505) 665-2017 E-mail: rem@lanl.gov

Enabling Technology #52: Generative Analysis

Brief Description of the Technology Area: This body of work seeks to develop a dramatically different, but complementary alternative for doing analysis. Generative analysis seeks to develop a new class of simulation environments that take advantage of the maturing area of "complex systems science." Instead of comparing scenario alternatives developed by the analyst, this new class of simulations generates alternatives that the analyst might never have conceived. In essence, the approach is to construct an ecology of simple interacting agents and the environment within which they exist. These agents have real-world analogs in that a plane is still a plane, a tank is a tank, etc. But we do not necessarily emulate the intelligent reasoning of humans who control the real-world organizations and equipment that these agents represent.

We rather take a constructionist or holistic view of the simulation system and develop these agents and their interactions among themselves and their environment with a view towards generating the macro systems properties in which we are interested. The overall force behavior is still apparent (i.e., mass is still mass, maneuver is maneuver, firepower and attrition are still the same), but the ways this behavior is achieved often can, and will, be the result of synthetic methods that are derived using a fundamentally different approach than emulating the way humans reason and make decisions. We rely very much on using relative strengths of the computer to create these ecologies of agents and imbue them with the ability to self organize, adapt, learn, and evolve over many thousands of trials to produce the ecology that is best capable of achieving the goals and objectives given to it by the analyst. The computational system that results cleverly searches a tremendous number of alternatives to find what works. It is during this process of searching many alternatives that the intuition we seek about the real systems begins to emerge as a by-product of the computation. When these kinds of demands are placed on the computing system, much, much faster than real time performance is required and humans cannot be in the computational loop. Moreover, we construct the system so that it can provide us with answers concerning both why and how it achieved the result.

Degree of Maturity: This technology area is in its infancy. Some significant foundational work has been done in fields such as transportation, but much remains to be done. The science of developing and using these advance computational systems is significant, but the potential return on this investment is enormous with respect to providing a much deeper understanding of the critical factors that make complex warfighting systems work effectively.

Potential Air Force Application Area(s)/Benefit to the Air Force: These kind of analysis systems are pervasive ranging from weapons systems COEAs, to Joint Warfighting Analysis, Requirements Studies, Test Evaluation, etc. In essence they potentially complement or augment all the ways simulations are used today.

Major Players/Leaders Doing Research in this Technology Area: In part, the Santa Fe Institute.

Comments: Current comparative analysis derives from the need to compare one force structure with another--both forces constrained by budget, threat, and other high level imperatives. In essence, analysts develop a force structure complete with equipment, doctrine, tactics, and plan (scenario) of employment against a threat force configured in a similar way. Terrain and weather are prescribed and the scenario causes the forces to interact to produce a result. The result is iterated until convergence is achieved between the analyst's vision for the outcome of the scenario, and the computer's "bean counting" calculus that tells analysts whether or not what they are trying to achieve is feasible. The first time through this process we call a baseline. We then introduce a delta in the force, such as changing its equipment and tactics, and repeat the process in order to compare it to the baseline. We do this as many times as we have alternatives. The goal is to allow decision makers to compare and contrast competing force/budget alternatives to hopefully build consensus for a decision. It is not necessarily to provide intuition about critical factors that make the force work effectively, other than as we attribute them to the representational calculus.

For some issues, this approach works pretty well. The problem we face occurs when we try to "make it better" to address issues for which it is not well suited. In essence, many believe that a scripted simulation system is made better by: (1) simulating phenomena in higher and higher "fidelity" and in more and more numbers of component interactions; and (2) putting humans in the loop as players to make decisions during execution of the simulation because we don't know how to get computers to make these decisions. We are beginning to believe that both of these approaches are inadequate for examining many issues of complex systems behavior (such as those you bring up) from the results of our ongoing simulation research at LANL.

Without dwelling on the details, we are finding that:

• More simulated components of systems (greater resolution) is not always better. There is a point during the reductionist approach of breaking down systems into more and more detail and more and more component interactions at which our ability to understand the overall macro system does not get better. In many instances, it arguably gets worse, because the macro behavior we seek has little to do with micro interactions being simulated.

• Higher fidelity is not always better. Mostly a corollary to the first point but in seeking to accomplish both of these goals, the simulation community is potentially embarking on development of a simulation system that is prohibitively expensive to develop, and so awkward and inflexible that it may be impossible to use effectively and maintain over time. Moreover, these systems are so slow and cumbersome that they only examine a very few of the many possible ways that future force systems can be developed and employed in future conflicts.

• The way to get computers to represent complex phenomena is not necessarily to emulate the human way of doing it. Our attempt to develop very sophisticated driver behavior models for transportation was successful at the micro level but an utter failure at the macro level. In other words while the simulated cars looked and acted like cars in the real world, their combined interactions failed to produce and predict congestion as we know it exists in the real world. We ultimately adopted a much simpler approach for representing driver behavior, one that produces

the correct macro level behavior for traffic. I am mindful of a quotation by Garry Kasparov after his first loss to "Deep Blue:" "If the computer makes the same move that I would make for completely different reasons, has it made an 'intelligent' move? Is the intelligence of an action dependent on who (or what) takes it?" The issue again is emergent behavior, in this case, macro intelligence of the simulated system and how best to achieve it. We are developing the science, concepts, and methods of a new generation of simulation systems and applying them to systems such as transportation and, hopefully soon, defense. Both approaches to analysis--comparative and generative--are important and both arguably deal with different sets of issues. It could well be the case that some combination of both offers yet another capability more powerful than either one alone.

Los Alamos Point of Contact:

Mr Ray Gordon
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos NM 87545
Phone: (505) 667-2205
E-mail: rgordon@lanl.gov

Enabling Technology #53: Model Abstraction via Solution of the Inverse Problem to Define a Reduced Order Model

Brief Description of the Technology Area: Model Abstraction Via Solution of the Inverse Problem to Define a Reduced Order Model expands the available classes of metamodels by supporting development of dynamical models that incorporate memory. This expansion allows generation of metamodels that include system dynamics so that metamodels can be developed where the past can influence the future. Defining the metamodeling problem in this manner adds a vast amount of existing research (realization theory and system identification methods) to the statistical (regression) methods currently used to approach the problem.

Degree of Maturity: Model Abstraction Via Solution of the Inverse Problem to Define a Reduced Order Model has been successfully applied to a number of Air Force metamodeling problems. The research requires knowledge of identification methods and their limitations. Expanded use of this technique requires development of an expert system that can be used by an analyst to develop metamodels of large-scale systems. This development is currently in process.

Potential Air Force Application Area(s)/Benefit to the Air Force: This technology is applicable in all areas of M&S. It can be used to support simulation analysis by reducing simulation results to a set of mathematical equations that can be easily analyzed. This technology can also be used in the integration of multiple simulations by approximating one of the simulations (or portions thereof) by a system of equations. It can also be used in the Verification, Validation, and Accreditation process by providing a direct, external, and efficient comparison of different models or simulations.

Major Players/Leaders Doing Research in this Technology Area:

Dr Don Caughlin,
Space and Flight Systems Laboratory.
1867 Austin Bluffs Parkway, Suite 202
Colorado Springs CO 80918-7864
Phone: (719) 593-3573
Fax: (719) 548 9127
E-mail: donc@mozart.uccs.edu

Enabling Technology #54: Intelligent Simulation Objects

Brief Description of the Technology Area: Intelligent computer-generated forces have long been discussed but have, as yet, remained an illusive and unobtainable goal. At the same time, this deficiency in credible C3I (Command, Control, Communication, and Intelligence) representation within combat simulations is generally acknowledged, the modern battlefield places an even greater reliance on performance in this area. The credible representation of command and control functions and the incorporation of effective, multisource, data fusion algorithms are central to the development of a viable, large-scale, synthetic battlefield environment.

Typically, behavior in combat simulations has been represented by rule-based, decision table, predicate statement-type logic structures which require, in many instances, supplemental "scripting" to insure they are doctrinally and tactically sound given the particular scenario context. Our approach uses a combination neural net and genetic algorithm to represent the cognitive process. This approach begins by capturing current or available knowledge in the form of a rule-based expert system (RBES). We then construct an artificial neural network equivalent of the RBES and "train" it, in a simulation environment, to minimize the error of the net's output relative to a given desired system output. We call this supervised training. Next, we attempt to maximize some measure of performance of the net as a controller, again in a simulation environment. This we refer to as production training. This accelerates the acquisition of knowledge or "learning," takes humans out of the loop, and uses genetic algorithms to mutate the input decision variables and thereby output "new" rules which we can capture and extend the knowledge base.

This work represents a paradigm shift in the representation and behavior of the simulation entities or "actors." Specifically, it takes advantage of the distinction between data structure and function in an object-oriented software approach and distinguishes/ compartments the behavioral function of an object into its physical and cognitive (command/control) components. It is the cognitive behavioral representation of the object that is the primary technical challenge addressed in this approach.

Degree of Maturity: The body of work to date has concentrated on developing a proof-of-concept simulation with adaptive, reasoning simulation objects. The specific goal was to demonstrate credible behavior of "intelligent" simulation objects in a simplified combat environment--though it will have general applicability to any simulation domain where representation of human behavior is an essential element.

To date, we developed mathematical methods to smooth the rule set input space, captured the rule set in five candidate neural network architectures, developed a criterion and appropriate performance measures for quantifying "capture-ability" of the rule set by each candidate neural network architecture, and run and evaluated the resultant networks against the criterion. Further, we are able to extract the new knowledge from the neural networks and modified the rule sets with this new knowledge. Emerging results continue to be encouraging. Research still needs to

be done to develop the general solution and examine applicability to aggregate entity simulation objects, e.g. mission packages.

Potential Air Force Application Area(s)/Benefit to the Air Force: This technology has been applied to several Army and Air Force systems, specifically: a simplified fire controller for a tank; a much more complex fire controller for an airborne laser; and a flight controller for an airborne laser. Each of these controllers has demonstrated individual adaptive control behavior. Ongoing work is looking at coordinated adaptive behavior--e.g., coordinating the flight and fire controllers on the airborne laser to achieve optimum performance of the system as a whole.

The primary benefit derived from this technology is the emergent rather than scripted behavior of the simulation entities. This is particularly important in conceptual systems for which tactics have not yet been developed. Moreover, this technological approach has produced rules which are identifiable and appear to be tactically sound. However, theoretical research concerning the production of dynamical behavior in simulations has led to issues that will have to be considered more carefully in adaptive approaches of this kind and engineering exploitations of which will serve to make simulations much more capable and fast running.

Major Players/Leaders Doing Research in this Technology Area: Not known.

Comments: Several Los Alamos National Laboratory unclassified reports have been published on our work in this technology area to date. Copies of these are available upon request.

Los Alamos Point of Contact:

Mr Ray Gordon
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos NM 87545
Phone: (505) 667-2205
E-mail: rgordon@lanl.gov

Enabling Technology #55: Dynamic Simulation Model of Complex Business System (Major Defense Acquisition Program)

Brief Description of the Technology Area: Technology is the F/A-18E/F Program Dynamics Model (PDM). PDM enables the dynamics of management decisions to maintain and/or alter the direction of development and delivery of advanced technology hardware in support of F/A-18E/F acquisition. PDM is a synthetic environment designed to emulate and forecast program performance. While deriving from the tradition of Systems Dynamics and Industrial Dynamics, it moves beyond to integrate modern management concepts such as Integrated Product Development Teams (IPDT), Concurrent Engineering, C/SCS, among others. The model is embedded in a user-friendly Windows interface that enables the outlook for the program to be analyzed by simulating realistic decisions to counter forces (external or internal) that might impact performance. Results are presented to program management to provide additional information to pending decisions.

Degree of Maturity: PDM is operational and used to support ongoing F/A-18E/F program management. However, PDM is driven by and calibrated to F/A-18 program performance data and would not be available for application to USAF programs. There is, however, a similar model that has been developed for the B-2 Program.

Potential Air Force Application Area(s)/Benefit to the Air Force: The generic approach of dynamic simulation of program management is the primary area in which such a technology would benefit the Air Force. This technology is directly beneficial, not only as it enables the unobtrusive and counterintuitive effects of decisions to be illuminated, but also as it requires acquisition programs to assemble critical performance data (often ignored) with which to manage and support the technology. The payoffs are in delivering on cost, on schedule, with improved quality.

Major Players/Leaders Doing Research in this Technology Area: Key players in this area of modeling and simulation are Pugh-Roberts Associates, Cambridge, MA (Mr Kenneth Cooper, President). B-2 Program Model is responsibility of Mr Chris Hernandez, Manager, Product Definition, Pico Rivera, CA. Chief scientist for F/A-18 Program Dynamics Model is Dr J. J. McIlroy (see below).

Name, Address, Phone Number, and E-mail:

Dr J. J. McIlroy
Program Director, Program Independent Analysis, F/A-18 Programs
Northrop Grumman Corporation
One Hornet Way
El Segundo CA 90245
Phone: 310-331-5409
Email: jmcilroy@world.northgrum.com

Enabling Technology #56: Object-Oriented Simulation

Brief Description of the Technology Area: Expanding the application of object-oriented techniques to the modeling (i.e., representation) and simulation of complex entities and systems, such as aircraft, sensors, weapons, and C4I systems, focusing primarily on how to represent the various types of relationships among these entities and systems, as well as the relationships between them and their human operators. Different types of such relationships include composition (e.g., between an aircraft and its wing), attachment (e.g., between an aircraft and a missile), as well as more general associations. This technology area attempts to raise the level of abstraction at which these relationships are modeled. The semantics of these relationships is particularly important, and goes well beyond what is currently supported in object-oriented programming languages, which still are capable of implementing the relationships between objects using simple pointers.

Degree of Maturity: While object-oriented programming is more than 25 years old, going back to the Simula programming language, the application of object-oriented principles to the modeling and simulation of complex systems is still a relatively immature area. It is only in the past 3-5 years that object-oriented principles have begun to be applied to large-scale systems.

Potential Air Force Application Area(s)/Benefits to the Air Force: Application areas include object-oriented intelligence databases and C2 systems as well as simulations for both training and analysis purposes. A common set of objects and their relationships will allow these diverse systems to interoperate with each other far more easily than is currently the case. The entities that make up both the friendly and opposing forces would map directly to objects in Air Force C4I databases and applications. This concept was identified in the DARPA War Breaker program, but was never really exploited. It also appears in the DMSO High Level Architecture (HLA) concept of Common Models of the Mission Space (CMMS).

Name, Address, Phone Number, and E-mail:

Mr Kevin C. Trott
PAR Government Systems Corporation
Phone: 315-738-0600
E-mail: kevin_trott@partech.com

Enabling Technology #57: Human Dynamic Modeling

Brief Description of the Technology Area: Human body dynamics modeling uses structural modeling techniques to predict crew motion, forces, and injury during ejection from aircraft, aircraft crashes, automobile accidents, and other hazardous events. It allows the user to describe the occupant, the seat and cockpit, any restraint systems, and the vehicle motion. The modeling techniques can provide an anthropometric body structure for any body size or gender. Using this information, the model calculates the forces on the body throughout the event and the resulting body motion. This information can then be used to predict injury or evaluate safety.

Degree of Maturity: This technology has been successfully applied to many Air Force programs. Some examples are simulations of head impact with a head-up display during a survivable C-17 crash, leg clearance during ejection from Joint Primary Aircraft Training System (JPATS) aircraft, and escape procedures during an emergency on a Joint-STARS aircraft. Further effort is needed to fully link the human modeling capabilities with ejection seat and control models. More detailed neck modeling capabilities are required to accurately predict injury with the new advanced helmet systems. Continued validation and injury criteria development is needed to properly model females and the new environments being simulated.

Potential Air Force Application Area(s)/Benefit to the Air Force: Human body modeling can be used to predict personnel responses to the forces of ejection, vehicle crashes, and other hazardous environments. It has been used to determine the safety of proposed structures in the aircraft cockpit before prototypes were built or costly tests conducted. It is also used to provide data that cannot be measured during a test, such as forces within the body, and to supplement test data with parameter variation simulations.

Major Players/Leaders in Technology Area:

Dr Louise Obergefell
Air Force Research Laboratory
(formerly Armstrong Laboratory) - AL/CFBV
2610 Seventh Street
Wright-Patterson Air Force Base OH 45433-7901
Phone: (513) 255-3665
DSN 785-3665
E-mail: lobergefell@al.wpafb.af.mil

Dr John B. Bomar, Jr.
Biodynamic Research Corporation
9901 IH West, Suite 1000
San Antonio, TX 78230
Phone: (210) 691-0281
E-mail: BOMARJB@brc-sat.mhs.compuserve.com

Enabling Technology #58: Human Interactive Mission Simulation

Brief Description of the Technology Area: Operator Integration Testbed. Advance the simulation technology by linking a flexible, instrumented, human interactive simulation testbed with Distributed Interactive Simulation (DIS) to evaluate the human interaction during complex mission simulation. Quantify the contribution of the aerospace crew system to mission effectiveness and trace the crew system's operational payoff during acquisition, with measures to assure clear accountability in design. This work fills a recognized need for human-system assessment technology in exploiting Distributed Interactive Simulation. Current technology fails to link the crew performance to operational measures of performance or effectiveness (MOPs/MOEs). Attempts to estimate the crew system payoff in the requirements phase almost never correlate with estimates made during test and evaluation. Current state-of-the art does not foster crew-centered design in full operational context. The DIS community understands the critical role of the human interactions in large-scale DIS exercises, and has publicly recognized the need to invest in this technology.

Degree of Maturity: Major milestones:

- Identify methods for embedding crew performance variables within system COEAs (FY97)
- Test and evaluate crew system MOPs and MOEs in DIS experiments (FY99)
- Establish design integration software tools for Operator Integration Testbed (FY99)
- Evaluate information management software tools for Operator Integration Testbed (FY00)
- Complete pre-design for an Operator Integration Testbed (FY00)
- Develop Operator Integration Testbed with installed performance measures (FY01)
- Demonstrate Operator Integrated Testbed in selected DIS exercise (FY01)

Potential Air Force Application Area(s)/Benefit to the Air Force: A clear understanding of the relationships between crew measures of performance and system measures of effectiveness has broad, immediate application to engineering development and T&E programs. Permits comparing crew technologies with other technologies in trade-off assessments. Products apply to the Theater Battle Arena, Synthetic Theater of War, Air Force Battle Labs, and Joint Warfighting Experiments.

Major Players/Leaders in This Technology Area:

Captain Scott L. Smith
Air Force Research Laboratory
(formerly Armstrong Laboratory) - CFHD
Human Engineering Division
2255 H Street
Wright-Patterson AFB OH 45433-7022
Phone: (513) 255-8914
DSN 785-8914
E-mail: ssmith@al.wpafb.af.mil

Dr Herbert H. Bell
Air Force Research Laboratory/HEA
6001 S. Power Road, Building 558
Mesa AZ 85206-0904
Phone: (602) 988-6561, DSN 474-6561
E-mail: herbert.bell@williams.af.mil

Lt Col Martin Stytz
Air Force Institute of Technology/ENG
2950 P Street
Wright-Patterson AFB OH 45433-7765
Phone: (513) 255-3576
DSN 785-3576
E-mail: mstytz@afit.af.mil

Comments: Work builds on successes from the Air Force Research Laboratory Crew-Centered Design Technology project (i.e., on-line crew-centered design process, software analysis and design tools, configurable cockpit simulator, and T&E workstation).

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Scott L. Smith, Captain, USAF
Same as above

Enabling Technology #59: Human Operator Cognitive Modeling for Mixed Level Analysis

Brief Description of the Technology Area: Models of human cognitive processes are generally performed at a level of specificity that makes them unusable components for systems-level or campaign-level models. Consequently, these widely focused models frequently do not include a functional representation of the human participants. Models of human operators and especially cognitive performance have been identified as a critical need of the modeling community. Current research is directed toward developing a model of crewmember workload and situation awareness for a Theater Missile Defense mission for both a single-seat and two-seat aircraft. The target level of detail for this effort will provide a model to be used as an input in models like TAC Brawler or EADSIM.

Degree of Maturity: A relatively new effort. Data collection on the first laboratory simulation experiment is near completion. Construction of a network model of the experiment is in progress.

Potential Air Force Application Area(s)/Benefit to the Air Force: Campaign-level models are becoming increasingly popular for many planning and training applications. Until validated human operator submodels are available, the scope of applications for these models is limited. This class of models is also needed for application to cockpit design evaluation.

Major Players/Leaders in Technology Area:

Gary B. Reid, Air Force Research Laboratory
(formerly Armstrong Laboratory) – CFHP, Human Engineering Division
2255 H Street, Wright-Patterson AFB OH 45433-7022
Phone: (513) 255-8749, DSN 785-8749 E-mail: greid@al.wpafb.af.mil

Mr Keith Hendy, Defense Civil Institute of Environmental Medicine
P. O. Box 2000, North York, Ontario, Canada

Mr Kevin Corker, NASA-Ames Research Center

Comments: This work is a major piece of an international joint effort. Under the auspices of The Technical Cooperation Program (TTCP), Human Resources and Performance Subgroup (Subgroup U), Technical Panel on Human Factors in Aircraft Environments (TP-7), researchers on this project are cooperating with other research teams in Great Britain, Australia, Canada, as well as other U.S. agencies. The teams will compare and contrast accuracy of workload and performance predictions from a variety of modeling approaches across a variety of operational missions. Only a large-scale competitive showdown of this sort will be effective in winnowing through the myriad of currently available modeling approaches to identify the most effective. The number and quality of participants enhances the potential for successful development of models that have application to a range of military and civilian missions.

Name, Address, Phone Number, and E-mail of Person Providing This Input: Mr Gary B. Reid, Same as above

Enabling Technology #60: Simulation Design and Evaluation Using Operator State Monitoring

Brief Description of the Technology Area: Assessment of simulation realism and the effects on the pilot typically is based upon the pilot's or operator's subjective judgments of the adequacy of the simulation. Psychophysiological measures of operator state can provide more objective assessment of simulator realism based upon the operator's physiological responses to simulation scenarios. These measures provide objective assessment of operator state. By comparing simulator-derived data to flight data, it is possible to make objective evaluations of simulator effectiveness. Psychophysiological measures such as brain waves, heart rate, eye blinks, and respiration provide objective assessment of the impact of the environment on the pilot. They have been found to be valid measures of mental workload and are related to the level of situation awareness. Further, these methods can provide assessment of training effectiveness and level of training. As crewmembers become proficient with a system, changes in their physiological state can be used to evaluate their progress. With ambulatory recording devices and available computer software, data collection is facilitated and data reduction is rapid. Data reduction is accomplished on-line in simulator environments.

Degree of Maturity: These procedures are already used in flight and laboratory environments to provide operator state assessment. More research needs to be done to directly compare simulator and flight environments and to model the relationship between them. We need to collect data from highly comparable simulation and flight scenarios to determine the relationship in a number of aircraft and mission types. We are currently exploring the use of neural networks to classify operator state. This work is going very well and promises to enhance our capabilities to accurately and reliably estimate operator state. Further work will improve these methods and permit incorporation into our Workload Assessment Monitor system. Standards need to be established to determine the level of improvement as crews progress through training. Criteria need to be established to determine when students are ready to advance to the next level. Also, criteria for individual skills will be evaluated so that they can be completed to a satisfactory level. Our Workload Assessment Monitor is available for on-line physiological data collection and reduction in simulator environments and includes brain wave, cardiac, eye blink and respiration analysis.

Potential Air Force Application Areas(s)/Benefit to the Air Force: This technology has many potential application areas in the Air Force. Test and evaluation programs have a great need for objective measures of operator workload and situation awareness to evaluate new and modified systems. Future generation crew stations will be able to incorporate operator state into system computers to provide appropriate adaptive aiding assistance to the operator to enhance mission effectiveness.

Major Players/Leaders in Technology Area: Dr Glenn F. Wilson, Armstrong Laboratory/CFHP, Human Engineering Division, Wright-Patterson AFB OH.

Comments: Numerous journal articles, chapters, and technical reports are available that describe our work. We are unique in that we conduct studies in both simulators and flight. We also have excellent laboratory facilities that we use to augment our simulator and flight work.

We are currently engaged in a research project with the Swedish Air Force to compare flight and simulator data using the same scenario. No other laboratory has the unique facilities and experiences that are available at the Air Force Research Laboratory.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Dr Glenn F. Wilson
AL/CFHP
2255 H Street
Wright-Patterson AFB OH 45433-7022
Phone: (513) 255-8748, DSN 785-8748
E-mail: GWILSON@FALCON.AL.WPAFB.AF.MIL

Enabling Technology #61: Define Visual Display Specifications through Human Performance Simulation

Brief Description of the Technology Area: This technology area was identified during the Visual System Evaluation Program (Vis-Eval) sponsored by ASC/YWE. During this evaluation, we found the image quality of the wide field-of-view (WFOV) visual display to be crucial in formation flying, target acquisition, and general situation awareness. Existing models of static peripheral vision are known to be oversimplified and do not possess the fidelity needed to adequately definite the WFOV display image quality requirement. The product of this effort will be an improved dynamic performance model of the human peripheral vision that will be applicable to all crew training systems which use a visual system to simulate the natural world.

Degree of Maturity: The new PC-based vision model can be used to predict resolution, contrast, and brightness needs for existing and future flight simulators.

Potential Air Force Application Area(s)/Benefit to the Air Force: The goal is to produce a display system specification based on human visual perception which will enable various tactical missions to be accurately and faithfully simulated. Otherwise, today's simulator deficiency will remain until fixed.

Major Players/Leaders in Technology Area:

Mr Brian H. Tsou
Armstrong Laboratory/CFHV, Human Engineering Division
2255 H Street
Wright-Patterson AFB OH 45433-7022
Phone: (513) 255-8896, DSN 785-8896
E-mail: btsou@al.wpafb.af.mil

Aerospace Vision Lab
Human Engineering Division
Armstrong Laboratory
Wright-Patterson AFB OH 45433

Comments: Preliminary research has been pushed by the aircrew flight simulation and training community.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Mr Brian H. Tsou
Same as above

Enabling Technology #62: Human Performance Modeling

Brief Description of the Technology Area: In the real world, particularly in wartime, conditions exist which make humans perform in a less than ideal way. Factors influencing human performance but which are rarely taken into account in existing models and simulations include fatigue, stress, environmental conditions (*e.g.*, temperature, precipitation, or time of day), communication breakdowns, chemical or radiation effects (exposure to agents or just wearing protective gear), injuries, and experience. The goal is to improve the accuracy of existing models and simulations by modifying the human performance factors that the models and simulations use.

Degree of Maturity: This technology is rapidly evolving for use in both military and civilian applications. Continued research and development is required to incorporate degraded human performance into high-level models and simulations effectively.

Potential Air Force Application Areas/Benefit to the Air Force: Realistic human performance modeling is required because existing models and simulations do not adequately account for human factors in their computations and may produce inaccurate results. Improving the reliability and accuracy of existing models and developing a methodology for integrating human factors into the development phase of new models should be a priority for the Air Force and the DoD. A effort to accurately model human performance is an excellent way to improve key models to represent missing aspects of air and space power, to begin the transition of current models to next generation of standards and technologies, and to avoid the pitfalls of low fidelity training.

Major Players/Leaders in Technology Area:

Dr Samuel Schiflett, Air Force Research Laboratory
Warfighter Training Research Division
2504 Gillingham Dr, Ste 1
Brooks AFB TX 78235-5104
Phone: (210) 536-3464, DSN 240-3464
E-mail: schiflett@apache.brooks.af.mil

Dr Mike Fineberg, Pacific-Sierra
1400 Key Blvd., Suite 700
Arlington, VA 22209
Phone: (703) 527-4975

Comments: A plan to integrate more realistic characteristics to represent human behaviors in models at the tactical and campaign level of Command and Control is currently being developed by AFRL (previously AL/CFTO) and HSC/XRS.

Name, Address, Phone Number, and E-mail of Person Providing This Input:
Dr Sam Schiflett - Same as above

Enabling Technology #63: Environmental Molecular Modeling (EMM)

Brief Description of the Technology Area: Molecular modeling is fast becoming an important tool in areas of chemistry, such as materials research and drug discovery research, that were heavily dominated by experimental approaches alone. Environmental research, however, is still heavily experimental in nature and has not capitalized upon advantages offered by molecular modeling. This is unfortunate given that the list of contaminants is growing rapidly (The Chemical Abstracts Service has catalogued one million new substances last year alone--any of which could pose a threat to the environment.). Though existing computational chemistry methods may be used for environmental applications, newer algorithms for electronic structure calculations are needed which offer greater speed and accuracy. Software based upon more powerful algorithms would offer an ability to sort through various possible fates of contaminants far more rapidly and with less expense than experimental programs. At the Air Force Research Laboratory (fomerly Armstrong Lab Environics Directorate) at Tyndall AFB, a new computational strategy was tested and proven to offer greatly increased speed and accuracy in performance of electronic structure calculations. The method is referred to by its inventor as a "Multi-domain Weighted Residual Method" and will be described in detail in a forthcoming issue of the Journal of Chemical Physics. The technology behind the calculation represents an interdisciplinary effort joining techniques found in engineering, chemistry, and physics applications.

Degree of Maturity: At 6.2 level of development; needs to be tested on multielectron systems in the context of Density Functional Theory. Thus far, tests have been performed on single-electron, multinuclear systems; results show up to an order of magnitude reduction in error and nearly an order of magnitude increase in speed over the most commonly used electronic structure package, GAUSSIAN 94.

Potential Air Force Application Area(s): Air Force-wide. May be applied to all potential contaminants, both airborne and groundwater. Most commonly, the computational approach will be used to obtain rate-constants for various reaction pathways (air or water) and determination of adsorption isotherms on materials of geologic significance.

Major Players/Leaders Doing Research in this Technology Area: Air Force Research Laboratory (formerly Armstrong Lab) Environics Dir; Gaussian, Inc.; and Schrodinger, Inc.

Comments: Two to three years are still needed to complete algorithm research. When mature, the overall approach will contribute substantially to AF ability to perform risk assessments on new substances undergoing consideration for AF use.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Dr Tom Stauffer, Air Force Research Laboratory (formerly Armstrong Lab - AL/EQC)
139 Barnes Drive, Suite 2, Tyndall AFB FL 32403
Phone: (904) 283-6059, DSN 523-6059
E-mail: Tom_Stauffer@ccmail.aleq.tyndall.af.mil

Enabling Technology #64: Risk Assessment/Dispersion Modeling

Brief Description of the Technology Area: The Rocket Exhaust Effluent Diffusion Model (REEDM) estimates toxic hazardous corridors (THC) from rocket exhaust. It uses basic Gaussion code to account for the dispersion of hot emissions from a mobile source. The Cape and Vandenburg AFB use this modeling for launch operations.

Degree of Maturity: REEDM is operational at both launch ranges. Improvements are being made constantly by the ACTA Inc.

Potential Air Force Application Area(s): Risk assessment regarding toxic plumes for nominal launches.

Major Players/Leaders Doing Research in this Technology Area: Air Force Research Laboratory (formerly Armstrong Lab) Environics Directorate, ACTA Inc., Yamada Arts and Sciences, and Kamada Science.

Comments: REEDM is used for go/no-go decisions at both ranges. The latest version is Version 7.07, recently completed by Randy Nymann of ACTA, Inc. at the 30th SW. REEDM may eventually be replaced by a more sophisticated code, such as Higher Order Turbulence Model for Atmospheric Circulation/Random Puff Transport and Diffusion (HOTMAC/RAPTAD).

Name, Address, Phone Number, and E-mail:

Capt Carolyn Vadnais
Air Force Research Laboratory
(formerly Armstrong Lab) - AL/EQ
139 Barnes Drive, Suite 2
Tyndall AFB FL 32403-5323
Phone: (904) 283-6249 DSN: 523-6249
E-mail: Carolyn_Vadnais@ccmail.aleq.tyndall.af.mil

Enabling Technology #65: Emissions Inventory/Dispersion Modeling

Brief Description of the Technology Area: Emission Dispersion Modeling System (EDMS) was developed in a joint Federal Aviation Administration (FAA) and Air Force Research Laboratory (formerly Armstrong Lab - AL/EQS) effort. The microcomputer-based system is an integrated emissions database and dispersion model, capable of treating multiple pollutant sources and receptors in the airport/air-base environment. The model runs in both screening and refined modes, facilitating environmental assessments related to new aircraft beddown, mission changes, runway expansions, etc. EDMS treats emissions of NOx, SOx CO, hydrocarbons, and particulates from point, area, and line sources.

Degree of Maturity: EDMS is in widespread use both in civilian and military applications, in part, because of an Environmental Protection Agency (EPA) ruling that designated EDMS a preferred guideline model for airport/air-base air quality assessment. The model is currently under revision to include indirect (induced) emissions, output files in text format, a Windows-based user interface, and better aircraft and support equipment emissions data.

Potential Air Force Application Area(s): This tool is accepted by the FAA and EPA and will allow all USAF bases with operational flight lines to maintain compliance with the Clean Air Act.

Major Players/Leaders Doing Research in this Technology Area: Air Force Research Laboratory (formerly Armstrong Lab Environics Directorate) and

Ms Diana Liang
Federal Aviation Administration
Office of Environment and Energy
Analysis and Evaluations Branch, AEE-120
800 Independence Ave SW
Washington DC 20591
Phone: (202) 267-3494
E-mail: dliang@mail.hq.faa.gov

Name, Address, Phone Number, and E-mail:

Capt Carolyn Vadnais
Air Force Research Laboratory
(formerly Armstrong Laboratory) - AL/EQ
139 Barnes Drive, Suite 2
Tyndall AFB, FL 32403-5323
Phone: (904) 283-6249; DSN 523-6249
E-mail: Carolyn_Vadnais@ccmail.aleq.tyndall.af.mil

Enabling Technology #66: Dispersion Modeling - Higher Order Turbulence Model for Atmospheric Circulation/Random Puff Transport and Diffusion

Brief Description of the Technology Area: Higher Order Turbulence Model for Atmospheric Circulation/Random Puff Transport and Diffusion (HOTMAC/RAPTAD), developed by Los Alamos National Lab, is being adapted/tested for Air Force use under Air Force Research Laboratory (formerly Armstrong Laboratory - AL/EQS) sponsorship. The system consists of a three-dimensional hydrodynamic windflow model and a Lagrangian diffusion model using "pseudo puffs" rather than particles. The model is prognostic in nature and treats complex terrain environments. Buoyant and dense gas capability is currently being incorporated.

Degree of Maturity: HOTMAC/RAPTAD is in use at several locations for modeling dispersion of toxics in the case of accidental spills. The model requires additional development for application to dispersion of toxic plumes from rocket launches and catastrophic aborts. This tool will be available for operational use by the summer of 1997.

Potential Air Force Application Area(s): HOTMAC/RAPTAD has excellent potential to replace current transport and diffusion models used for toxic risk assessment at the space launch ranges.

Major Players/Leaders Doing Research in this Technology Area: Air Force Research Laboratory (formerly Armstrong Lab Environics Directorate) and

Dr Ted Yamada
YSA Corporation, Inc.
Rt 4 Box 81-A
Santa Fe NM 87501
Phone: (505) 989-7351
E-mail: ysa@rt66.com

Name, Address, Phone Number, and E-mail:

Capt Carolyn Vadnais
Air Force Research Laboratory
(formerly Armstrong Laboratory) - AL/EQ
139 Barnes Drive, Suite 2
Tyndall AFB, FL 32403-5323
Phone: (904) 283-6249; DSN 523-6249
E-mail: Carolyn_Vadnais@ccmail.aleq.tyndall.af.mil

Enabling Technology #67: Dispersion Modeling - Fuel Jettison Model

Brief Description of the Technology Area: Fuel Jettison Simulation (FJSIM) - Fuel jettisoned by aircraft in flight may pose an environmental hazard. The recent Air Force conversion from JP-4 jet fuel to the less volatile JP-8 means that the likelihood for significant groundfall of jettisoned fuel is substantially increased. FJSIM is a Windows-based model that estimates the location, areal extent, and magnitude of ground contamination due to fuel jettisoned during flight, as well as the time-dependent reduction of ground level concentration due to evaporation. The model includes a verified multicomponent fuel evaporation model, meteorological effects, realistic fuel jettisoning information including fuel port locations and dimensions for each aircraft type, fuel flow rates, airspeeds, and aircraft wake effects.

Degree of Maturity: The initial version of FJSIM will be fielded in June 1996.

Potential Air Force Application Area(s): All Air Force environmental managers (Air Force, major command (MAJCOM), and air-base levels).

Major Players/Leaders Doing Research in this Technology Area: Air Force Research Laboratory (formerly Armstrong Laboratory Environics Directorate) and

Dr Milt Teske
Continuum Dynamics, Inc.
PO Box 3073
Princeton NJ 08543
Phone: (609) 734-9282 x-109
E-mail: milt%cdi@princeton.edu

Name, Address, Phone Number, and E-mail:

Capt Carolyn Vadnais
Air Force Research Laboratory
(formerly Armstrong Laboratory) - AL/EQ
139 Barnes Drive, Suite 2
Tyndall AFB FL 32403-5323
Phone: (904) 283-6249; DSN 523-6249
E-mail: Carolyn_Vadnais@ccmail.aleq.tyndall.af.mil

Enabling Technology #68: Decision Support System for Compliance

Brief Description of the Technology Area: The development of Emission Reduction Planning Model (ERPM) by USACERL, Air Force Research Laboratory (formerly Armstrong Laboratory - AL/EQS), and the EPA will create a prototype decision support system, by using artificial intelligence tools, that will assist facilities in establishing optimal, cost-effective strategies for maintaining compliance with air pollution regulation and permit requirements. At the end of the development, ERPM will ultimately provide a state-of-the-art decision support system to aid environmental personnel in determining areas of potential violations and compliance options, thus leading to installation-specific, cost-effective, air pollution compliance strategies. Moreover, DOD-wide use of the decision support system will provide consistency in the treatment of air pollution problems.

Degree of Maturity: The initial version of ERPM will be available in late 1997.

Potential Air Force Application Area(s): Users will be major command and base-level environmental planners and compliance monitors.

Major Players/Leaders Doing Research in this Technology Area: Air Force Research Laboratory (formerly Armstrong Laboratory Environics Directorate) and,

Mr Mike Kemme
Environmental Engineering Division
Environmental Sustainment Lab
US Army Corps of Engineers
Construction Engineering Research Lab (CERL)
Phone: (217) 373-4554
E-mail: m-kemme@cecer.army.mil

Name, Address, Phone Number, and E-mail:

Capt Carolyn Vadnais
Air Force Research Laboratory
(formerly Armstrong Laboratory) - AL/EQ
139 Barnes Drive, Suite 2
Tyndall AFB, FL 32403-5323
Phone: (904) 283-6249; DSN 523-6249
E-mail: Carolyn_Vadnais@ccmail.aleq.tyndall.af.mil

Enabling Technology #69: Optical Radiation Effects Simulation

Brief Description of the Technology Area: Optical radiation effects-simulation attempts to predict the effects of lasers on the human eye and skin, structures, and sensors. Accurately modeling these effects takes atmospheric conditions, terrain, and lighting conditions into account. Effects on the human eye include flashblindness, glare, lesions, and hemorrhages. Sensor and structure effects include signal saturation and damage. The ability to simulate laser effects in this manner has not previously existed. Additionally, the ability to incorporate zero time-of-flight weapons and their effects into current simulations creates a more accurate and robust representation of the real world.

Degree of Maturity: Currently, this technology is being incorporated into two Air Force programs: the Integrated Laser Personnel Effects Model (ILPEM) and the Laser Threat Analysis System (LTAS).

Potential Air Force Application Area(s)/Benefit to the Air Force: The capabilities of this simulation can be utilized in mission planning, threat/vulnerability analysis, mission rehearsal, and training range safety. Analysts and mission planners will be able to evaluate optical radiation threats and produce results vital to ascertaining the total threat impact. Continuing the "train as we fight" philosophy, this simulation can assess the risk of laser use on training ranges and evaluate the requirement for use of laser protection.

Major Players/Leaders Doing Research in this Technology Area:

Ms Christina Richardson
TASC, Inc.
750 East Mulberry Ave., Suite 302
San Antonio TX 78212
Phone: (210) 536-3038
E-mail: cerichardson@tasc.com

Capt Howard Gleason
Armstrong Laboratory
Optical Radiation Division
8111 18th Street
Brooks AFB TX 78235-5215
Phone: (210) 536-3039; DSN: 474-3039
E-mail: howard.gleason@platinum.brooks.af.mi

Comments: Additional information can be found on the Optical Radiation Division home page at http://www.brooks.af.mil/AL/OE/oeohome.htm.

Enabling Technology #70: Space Simulation Framework

Brief Description of the Technology Area: The Spacecraft Simulation Toolkit (SST) is being designed and built to be a general space systems simulation framework to support:

- spacecraft design, development, and analysis with measures of performance (MOPs) and effectiveness (MOEs),
- spacecraft virtual prototyping, space systems concurrent engineering and acquisition, and
- interoperability with wargaming exercises for realistic training, operations, and concept of operations/doctrine development via DIS, ALSP, and HLA protocols.

The SST is an advanced, flexible, visual programming development environment allowing one to "build" high-fidelity spacecraft on the computer via newly developed software objects or legacy space systems models integrated and encapsulated in Khoros and accessed through pull-down menus or libraries with a mouse. These models can be replicated to represent a full satellite constellation supporting surveillance, navigation, communications, missile warning, and weather functions. The SST includes the real-time impact of real-world environmental effects on spacecraft performance. Once fully populated, the SST will model all relevant components/subsystems/systems of the spacecraft. These models will be attached through an interface broker, dynamic interface specification, and standardized I/O requester to a common spacecraft database with both simulation/functional data and design/physical data. This will allow the simulation to maintain and update the state and dynamics of the simulated spacecraft and environment for real-time applications, restarts, and analyses. Currently, the SST has a DIS interface with standardized PDUs allowing an SST-built satellite to participate in wargaming exercises and to facilitate military utility assessments of the simulated satellite system.

This approach is different than the usual stovepiped, one-of-a-kind systems models developed by today's space System Program Offices (SPOs). It offers a standardized, cross platform-compatible, easy-to-use, simulation framework for both analysts and developers, and allows the product center and space command staffs to simulate candidate space systems for competitive evaluations or operational implementations before "metal is cut."

Degree of Maturity: Prototypes space systems in the SST were demonstrated in an Advanced Distributed Simulation (ADS) and DIS exercise, i.e., Warfighter 95 held at the Theater Air Command & Control Simulation Facility (TACCSF) in December 1995 and sponsored by AF/XOM. The purpose was to build an ADS environment that merged constructive simulation, virtual simulators, and live fly aircraft to exercise battlestaffs, command and control, and shooters in the conduct of theater air defense missions. Requirements included a real-time air picture in the Air Operations Center and use of real tactical data links to assist in displaying an accurate air situation via a distributed network. The SST provided a current operational Defense Support Program (DSP) Simulation, a notional Advanced Electro-Optical Warning System which included real-time weather and clouds affecting launch detection, and a global-space-down-to-theater stealth visualization tool (SpaceVIS) also responding to DIS PDU's.

Potential Air Force Application Area(s) / Benefit to the Air Force: Historically, M&S has treated narrow ranges of the technical aspects of space systems design, manufacturing, testing,

launching, and operating AF satellites. This has limited the effectiveness of M&S in systems acquisition. What is currently needed is a general space M&S methodology that models, in adequate technical detail, components/subsystems/systems and their interactions to evaluate total satellite capability and performance in a realistic, space-earth environment. The specific benefits of this kind of development to the Air Force include:

- reducing the cost and risk of acquiring future satellite systems,
- improving concept of operations/doctrine development for space systems,
- improving training of operators up to command staff levels on the use of space systems, and
- demonstrating the impact of current and future satellite systems on the warfighter.

Major Players/Leaders in Development:

Dr Richard K. de Jonckheere, Air Force Research Laboratory (formerly Phillips Laboratory)
Kirtland AFB, NM 87117-5776
Phone: (505) 846-5054 E-mail: dejonckr@plk.af.mil

Ms Terri Franklin, Photon Research Associates, San Diego CA
Phone: (619) 455-9741
E-mail: tlf@kirk.photon.com

Mr Mark Young, Khoral Research Inc., Albuquerque NM
Phone: (505) 837-6500
Email: young@khoral.com

Mr Dave Gadd, Air Force Research Laboratory (formerly Wright Laboratory)
Wright-Patterson AFB OH 45433-5000
Phone: (513) 255-1115
Email: dgadd@mbvlab.wpafb.af.mil

Comments: The ability to "fly" before you "build" is near reality with current simulation technology. This ability is critical to the warfighter in wargame simulations which must now include realistic space assets and threats. The SST is described in PL-TR-96-1050; under the Space Systems Simulation Framework in PL/VTQ's home page at http://www.plk.af.mil/PLhome/VT/vtq-modsim-home.html; and in some of the charts in the PL M&S home page at http://www.plk.af.mil/ORG_CHART/DS/SC/CSC/ms/index.html. The system for real-time environmental effects was developed under DMSO sponsorship and presented at the 12th DIS Workshop in Mar 95 (Paper #95-12-070, Prototyping and Experimentation of a Distributed Synthetic Environment for E^2DIS).

Name, Address, Phone Number, and E-mail:

Dr Richard K. de Jonckheere
Air Force Research Laboratory (formerly Phillips Laboratory)
Kirtland AFB NM 87117-5776
Phone: (505) 846-5054 E-mail: dejonckr@plk.af.mil

Enabling Technology #71: Network-Based Distributed Computing Systems

Brief Description of the Technology Area: JAVA is a programming language environment. More precisely Java is three things: an object-oriented programming language, a WEB browser, and a software distribution mechanism" (*Aerospace America,* April 1996, pages 12 - 14). For M&S, it can be used to remotely run M&S simulation programs on remote workstations; thereby, reducing redundancy and cost. The difference will stand out when we can run programs on the WEB and use input/output files from terminal workstation M&S software packages. The significance is that simulations can be run simultaneously, synergistically, and on PCs, Macs, and workstations that do not have the software applications on their hard drive. Also, M&S analysts can share data readily.

Degree of Maturity: JAVA is mature and platform independent.

Potential Air Force Application Area(s)/Benefit to the Air Force: Air Force research and development can be accomplished with less barriers with in-house researchers and analysts with the academic community and contractor scientists and engineers.

Major Players/Leaders Doing Research in this Technology Area: Sun Microsystems, http://java.sun.com/

Comments: Review the World Wide Web sites for information and applets reviewed in the April 1996 issue of Aerospace America, pgs 12-14. Convince NASA to place its application software such as the PC-based and UNIX workstation-based POST (Program to Optimize Simulated Trajectories) and OTIS (Optimal Trajectories by Implicit Simulations) on the Internet. Afterward, M&S can exploit the JAVA utility and use the latest version, NASA-developed software. Likewise, M&S can put their applications on the Internet. It will be an efficient method for allowing M&S take their archive list of software and having the widest distribution for all M&S analysts.

Name, Address, Phone Number, and E-mail:

Mr Francis G. McDougall
Air Force Research Laboratory
(formerly Philipps Laboratory) - OLAC PL/RKBA)
5 Pollux Drive
Edwards AFB 93524-7048
Phone: (805) 275-5582, Fax: (805) 275-5852
E-mail: mcdougallf@lablink.ple.af.mil

Enabling Technology #72: Cost Analysis Tool for Space Transportation Systems

Brief Description of the Technology Area: TRANSCOST: Statistical-Analytical Model for Cost Estimation and Economic Optimization of Space Transportation Systems. This model calculates development costs of propulsion-related submodel structures, LRE (liquid rocket motor), SRM(solid rocket motor), expendable ballistic stages, winged orbital systems, advanced high speed aircraft. It also calculates vehicle recurring costs which includes the "learning factor" cost impact as well as calculates the flight operations cost model. Because there is a scarcity of cost models application software with a measurable level of fidelity, it is important to know where they are available. As for RKBA, we have not acquired this package but, instead, have only created rudimentary spreadsheets without any type of statistical distribution. Therefore, we came up with a unique cost for systems without any statistically valid cost spread. With a 20-year, worldwide database, it is possible to get meaningful data to estimate costs from TRANSCOST.

Degree of Maturity: As of the 1988 edition, it has taken into account a database of over 20 years for space transportation systems.

Potential Air Force Application Area(s)/Benefit to the Air Force: Cost should be treated equally as any other variable related to propulsion analysis such as mass fraction, isp, thrust, pressure, altitude, flight trajectory angles, etc.

Major Players/Leaders Doing Research in this Technology Area:

Mr Dietrich E. Koelle
MBB Space and Communications and Propulsion Systems Division
PO Box 801169, D-8000
Munich 80 Germany

Comments: Reference MBB report # URV-180 (88)

Name, Address, Phone Number, and E-mail:

Mr Francis G. McDougall
Air Force Research Laboratory
(formerly Phillips Laboratory) - OLAC PL/RKBA
5 Pollux Drive
Edwards AFB 93524-7048
Phone: (805) 275-5582 Fax: (805) 275-5852
E-mail: mcdougallf@lablink.ple.af.mil

Enabling Technology #73: Trajectory Analysis

Brief Description of the Technology Area: POST (Program to Optimize Simulated Trajectories) PC version. POST on the UNIX workstation has been an RKBA analysis tool for modeling launch vehicles such as Atlas, Delta, Titan, Single Stage to Orbit, and Shuttle. NASA now has a PCc version of this modeling software. With a PC-base program and faster Pentium-based PCs, this software could reach a wider audience. If it is on a server and combined with the JAVA Web server utility, widest distribution to the M&S community is possible.

Degree of Maturity: First edition.

Potential Air Force Application Area(s)/Benefit to the Air Force: The PC format enables a trajectory analyst to have portability for this industry standard program originally developed by Martin Marietta for the Shuttle program.

Major Players/Leaders Doing Research in this Technology Area:

Mr Dick Powell
Space Systems Division, NASA
Langley Research Center
Phone: (804) 864 -4506

Name, Address, Phone Number, and E-mail:

Mr Francis G. McDougall
Air Force Research Laboratory
(formerly Phillips Laboratory) - OLAC PL/RKBA
5 Pollux Drive
Edwards AFB 93524-7048
Phone: (805) 275-5582 Fax: (805) 275-5852
E-mail: mcdougallf@lablink.ple.af.mil

Enabling Technology #74: Maui Image Processing

Brief Description of the Technology Area: Air Force Maui Optical Station provides image processing research and support of the AFSPC mission for space surveillance. New processing techniques are being investigated for providing real-time imagery and radiometric signatures of space objects from ground-based telescopes. Methods being studied include speckle imaging and linear phase retrieval, space variant blind deconvolution, and super resolution from invariant sensor measurements. This project requires 80 unclassified and 20 classified nodes of the IBM SP2 at MHPCC with additional support from Silicon Graphics and Sun workstations. Typical runs take approximately one hour on 32 nodes (unclassified) and 5,000 runs/year are needed. Classified jobs run on 16 nodes taking roughly 0.25 hours and 3,000 runs/year are needed. Projected needs estimate the use of 64 nodes for two hours per job at a frequency of 5,000 runs/year for unclassified work, and 64 nodes for 0.25 hours per job at a frequency of 4,000 runs/year for classified work. Major challenges for the ability to move this application to scalable parallel systems include funding for software engineering support and communications between remote site and MHPCC. Overall data transfer requirements are currently at 35 GB and are projected to increase to 70 GB for the next few years. The maximum acceptable transfer time that can be tolerated is eight minutes.

Degree of Maturity: Immature capability exists now, but should improve over the next 10 years.

Potential Air Force Application Area(s) / Benefit to the Air Force: Potentially could provide real-time identification of unknown space objects.

Major Players/Leaders in Development:

Major Dimmel
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LIMM
Phone: (808) 874-1540

Name, Address, Phone Number, and E-mail:

Lt Col Marc Hallada
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LID
Phone: (505) 846-4031
E-mail: HalladaM@plk.af.mil

Enabling Technology #75: Chemical Oxygen-Iodine Laser Modeling

Brief Description of the Technology Area: Chemical Oxygen-Iodine Laser (COIL) Technical Development develops and demonstrates a modeling capability for oxygen-iodine laser systems, to include 3D iodine injection, COIL chemical kinetics, and laser resonator physics. The code involves the Navier-Stokes equation for a 3D geometry with binary mixing. Most of the runs to date have been run on the Cray C90. Each job (study) entails 20-30 individual runs, each of 8 cpu/hr duration, and requiring up to 256MB of memory. The queuing system for the C90 allows for runs to be executed for 8 contiguous hours, before it is removed from the queue and recycled in the batch queuing system. The recycling time can take up to 3 days leading to a job turnaround time of up to 80 days per study.

Recently, the code has been ported to a single-wide node of the IBM SP2 at MHPCC, which has roughly 1/4 the speed of a C90 processor. However, in a 24-hr queue at MHPCC with a 1 ½-day batch queue recycling time, the overall turnaround time is again roughly 80 days. As a consequence of this, 3 dedicated 1GB wide nodes were reserved to run dedicated serial jobs. An initial investigation into parallelizing the code has been initiated.

The simulations involve extensive storage capability, partially to ensure checkpointing. Remote storage would minimize large data transfers. The challenges to this project are accessibility to dedicated processors to run long jobs. A study is needed to see if the inherent algorithms can be made to reformulate the code to run efficiently in parallel.

Degree of Maturity: Immature capability exists now, but should improve over the next 30 years.

Potential Air Force Application Area(s) / Benefit to the Air Force: Accurate modeling of COIL systems could finally result in laser beams that could penetrate thick atmospheres clouds, and water.

Major Players / Leaders in Development:

Dr Truesdell
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LIDB
Phone: (505) 846-4031

Name, Address, Phone Number, and E-mail:

Lt Col Marc Hallada
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LID
Phone: (505) 846-4031
Email: HalladaM@plk.af.mil

Enabling Technology #76: Laser Propogation

Brief Description of the Technology Area: The Airborne Laser (ABL) requires the development of atmospheric propagation models consistent with experimental data and development of simulations of laser tracking experiments. Future work will entail assessment of the ABL contractor designs for tracking and adaptive optics, and to provide support for ABL design efforts.

The computations for the models are FFT dominated so that a few Golfs, or higher, are desirable. Codes have been currently running on the C90 and the IBM SP2 at MHPCC, typically on 16 nodes. Run times are currently 2-3 hours, 500 runs/year and projected to increase to 10-12 hours at 150 runs/year.

Degree of Maturity: Immature capability exists now, but should improve over the next five years.

Potential Air Force Application Area(s) / Benefit to the Air Force: Completion of the ABL system could provide a flexible Theater Missile Defense device that could protect our military, allies, and nation from launched ballistic missiles.

Major Players / Leaders in Development:

Lt Col O'Keefe
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LIAE
Phone: (505) 846-4016

Name, Address, Phone Number, and E-mail:

Lt Col Marc Hallada
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LID
Phone: (505) 846-4031
Email: HalladaM@plk.af.mil

Enabling Technology #77: Airborne Laser Design

Brief Description of the Technology Area: Airborne Laser (ABL) Aerodynamic Design requires an optimized system design and wind tunnel verification for ABL leading to improved system performance. The purpose of this work is to enable ABL for theater missile defense. This work is performed mainly on the Cray C90, requiring a few Golfs, 50-100 hours of run time, up to 1GB of memory, and 2 GB of archival storage. Data transfers are projected to be as large as 1GB, on the order of 100-200 times a year, with an acceptable ceiling of 15 minutes. The codes here involve finite elements, and implicit and difference schemes. The challenges to this work are the manpower to do the parallel code conversion and optimization.

Degree of Maturity: Immature capability exists now, but should improve over the next 10 years.

Potential Air Force Application Area(s) / Benefit to the Air Force: Completion of the ABL system could provide a flexible Theater Missile Defense device that could protect our military, allies, and nation from launched ballistic missiles.

Major Players / Leaders in Development:

Capt Ching
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LIAF
Phone: (505) 846-5049

Name, Address, Phone Number, and E-mail:

Lt Col Marc Hallada
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LID
Phone: (505) 846-4031
Email: HalladaM@plk.af.mil

Enabling Technology #78: Semiconductor Laser Analysis

Brief Description of the Technology Area: High Power Semiconductor-Laser Technology requires full diffractive modes with complex gain/index for limited size and geometry diode lasers, including DFB and DBR devices. The projected scope of this work is to develop the above modes to handle arbitrary size/geometry diode lasers including large-scale laser arrays. This work is dominated by large 2D FFTs and complex matrix inversions. The codes currently can run up to 2-3 hours on the Cray C90 at approximately 200 runs/year and increasing to 500/year. Memory requirements are modest, 5-32 MB with few Mbs needs for storage. With the inclusion of time, however, to study dynamics, these requirements would increase drastically. Since parallel FFT and matrix inversion software exists, the challenges to this project are the resources and manpower to covert this code to run on scalable parallel systems.

Degree of Maturity: Immature capability exists now, but should improve over the next five years.

Potential Air Force Application Area(s) / Benefit to the Air Force: Solid-state diode lasers are uniquely rugged and applicable for many military laser applications. Increased efficiency in these systems could result in a higher power transfer (more heat in the beam).

Major Players / Leaders in Development:

Mr Pchelkin
Air Force Research Laboratory
(formerly Phillips Laboratory) PL/LIDA
Phones: (505) 846-4758

Name, Address, Phone Number, and E-mail:

Lt Col Marc Hallada
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LID
Phone: (505) 846-4031
Email: HalladaM@plk.af.mil

Enabling Technology #79: Passive Scalar Models

Brief Description of the Technology Area: The purpose of the Dynamics of a Passive Scalar in a Turbulent Jet effort is to study the effects of turbulent fluctuations on optical propagation and to develop a model using passive scalar measurements to predict the induced optical phase error. This project will perform linear stochastic and chaotic estimation, and flowfield modeling of actual experiments. The computation requires 2 hours/run at 200 runs/year with 256 MB of memory and 1-2GB of storage. The codes are dominated by FFT and correlation computations and would lend itself to parallelization. Desired advantages to remote HPC centers would be easier access and manipulation of data.

Degree of Maturity: Immature capability exists now, but should improve over the next five years.

Potential Air Force Application Area(s) / Benefit to the Air Force: Understanding the optical effects of a dynamic atmosphere allow us to more effectively compensate for the loss and dispersion of light so as to make more effective telescopes, lasers, and multispectral sensors.

Major Players / Leaders in Development:

Dr DeHainaut
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LIMS
Phone: (505) 846-3262

Name, Address, Phone Number, and E-mail:

Lt Col Marc Hallada
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LID
Phone: (505) 846-4031
Email: HalladaM@plk.af.mil

Enabling Technology #80: Integration of Multidimensional Models

Brief Description of the Technology Area: Modeling of equations describing the nonlinear dynamics of optical parametric oscillators used for frequency conversion, in 2, 3, and 4 dimensions. The study wishes to perform a full 4D analysis of the three-wave mixing equations and finite element modeling of thermal effects. The project goal of this work is an integration of multidimensional modeling with thermal effects. Currently, this code is running on the Cray C90 for the speed of its intrinsic 2D FFT. The code takes approximately one-half hour to run at 2,000 runs/year, currently requiring 15-20 MB of memory, handling 4-5 GB files and demanding 20-25 GB of archive storage. The inclusion of a 4th dimension would require the need for an efficient 3D FFT. Memory and storage sizes would increase dramatically. Parallelization is being explored for this code since 3D parallel FFT routines exist and would be able to handle the large data sets. For parametric studies, efficiency, performance, and speed are the criteria for any HPC. It is projected that this work will require 500-2,000 cpu hours/year on both the C90 and the IBM SP2 at MHPCC in the near future. Challenges to this project are manpower to help with the conversion of the code to scalable parallel architectures.

Degree of Maturity: Immature capability exists now, but should improve over the next five years.

Potential Air Force Application Area(s) / Benefit to the Air Force: Learning to manipulate light has ramification in several areas including optical processing, improved optical communications, and multispectral sensor analysis.

Major Players / Leaders in Development:

Dr Clayton
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LIDN
Phone: (505) 846-4750

Name, Address, Phone Number, and E-mail:

Lt Col Marc Hallada
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LID
Phone: (505) 846-4031
Email: HalladaM@plk.af.mil

Enabling Technology #81: Hyperspectral Image Modeling

Brief Description of the Technology Area: The purpose of the Hyperspectral Imaging study is to investigate satellite identification using hyperspectral data. This would allow for improved ability to identify satellites, mission, construction, and origin. The code requires from 256 to 512 processors on the IBM SP2 at MHPCC, with 0.5 hours of execution time at 100 runs/year. The memory requirements are 225 MB with 250 MB file sizes. This work is dominated by FFT computations.

Degree of Maturity: Immature capability exists now, but should improve over the next five years.

Potential Air Force Application Area(s) / Benefit to the Air Force: The goal of a real-time identification and analysis of distant vehicles could provide us information required for the most effective response. While the object of this work is to identify spacecraft, similar processes could be used to identify distant missiles, aircraft, tanks, or other objects.

Major Players / Leaders in Development:

Mr Czyzak
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LIMI
Phone: (505) 846-4844

Name, Address, Phone Number, and E-mail:

Lt Col Marc Hallada
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LID
Phone: (505) 846-4031
Email: HalladaM@plk.af.mil

Enabling Technology #82: Adaptive Optics Simulation

Brief Description of the Technology Area: The purpose of the Scalable Adaptive Optics Performance project is the analysis and simulation of Adaptive Optics Systems for atmospheric turbulence compensation and image post-processing by large ground-based telescopes. The project goals are to develop scalable versions of the adaptive optics analysis package with imaging codes such as blind deconvolution and deliver them to the DoD Scalable Software library with reports documenting the algorithms and code structure. For these applications, speeds up to 32 Golfs are needed, requiring up to 200 nodes of the IBM SP2 at MHPCC. The computations require up to 8 hours to run at 100 runs/year and demand 500 MB of memory, 128 MB file sizes and 5 GB of archival storage. File transfers of 32 MB are needed at 1,000 transfers per year with a maximum acceptable transfer time of five minutes.

Degree of Maturity: Immature capability exists now, but should improve over the next 10 years.

Potential Air Force Application Area(s) / Benefit to the Air Force: Understanding the optical effects of a dynamic atmosphere allows us to more effectively compensate for the loss and dispersion of light so as to make more effective telescopes, lasers, and multispectral sensors.

Major Players / Leaders in Development:

Major Leatherman
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LIGR
Phone: (505) 846-8923

Name, Address, Phone Number, and E-mail:

Lt Col Marc Hallada
Air Force Research Laboratory
(formerly Phillips Laboratory) - PL/LID
Phone: (505) 846-4031
Email: HalladaM@plk.af.mil

Enabling Technology #83: Computer-Generated Forces

Brief Description of the Technology Area: One of the major roadblocks preventing the use of Distributed Virtual Environments (DVEs) for training and mission planning/rehearsal is the limited number of simulators available with which to populate a DVE. The employment of Computer-Generated Forces (CGFs) within a DVE dramatically increases the number of entities in a simulated training environment. However, current CGF entities display limited perceptual and cognitive behaviors. These limitations produce behaviors that make CGFs easily distinguishable from human-controlled forces in the simulated environment. Unfortunately, these CGFs can be defeated using methods ineffective against humans. To model the human characteristics, it is necessary to deal with uncertainty, ambiguity, and approximation. Current research focuses on using artificial intelligence techniques such as case-based reasoning, expert systems, and fuzzy logic to develop CGFs that exhibit the complex characteristics of human decision making and behavior.

Degree of Maturity: CGF technology has varying degrees of maturity. Simple CGFs with limited intelligence are available and used in DVEs today. However, their limited intelligence also gives them limited utility. Several institutions are researching architectures for putting intelligent agents into CGFs. CGFs trained with knowledge of tasks and functions are reaching a usable maturity level. However, human-like intelligence is still at a basic development level. Significant research remains to be done before realistic behaving CGFs can be used to populate a DVE.

Potential Air Force Application Area(s) / Benefit to the Air Force: A realistic theater-sized air war requires far more aircraft than can be provided by the current number of manned simulators. Both Red and Blue forces must be present and trained in appropriate missions, roles, and tactics. Development of computer-generated air forces will close the gap between what is available and what is needed. Additionally, as new tactics are developed, they can be tested against validated and verified behavioral models programmed into the CGFs. The advent of behaviorally human-like CGFs will present the Air Force with opportunities, such as large-scale realistic mission rehearsals, never before possible.

Major Players / Leaders in Development:

Lt Col Martin Stytz and Dr Eugene Santos, Jr.
Air Force Institute of Technology
Phone: (513) 255-9270
E-mail: mstytz@afit.af.mil   esantos@afit.af.mil

Dr John Laird
Associate Professor, University of Michigan
Phone: (313) 747-1761
E-mail: laird@umich.edu

Capt Mark Edwards
Air Force Research Laboratory (formerly Phillips Laboratory), Geophysics Directorate
Phone: (617) 377-4008   E-mail: medwards@plh.af.mil

Enabling Technology #84: Joint Modeling and Simulation System (J-MASS)

Brief Description of the Technology Area: J-MASS will provide a common environment for tactical modeling across the requirements, development, acquisition, and test process. Coordinated efforts are currently underway to populate the system with authoritative representations of Air Force and threat systems (e.g., surface-to-air missiles, aircraft, etc.) that interoperate and comply with J-MASS standards. J-MASS provides the domain experts with software structural standards that promote the development of reusable, modifiable, maintainable, interoperable, and more easily validated models and model components. These standards are implemented through a collection of user-friendly tools that assist the domain experts in building models. With J-MASS, the bottom line is to improve the consistency, credibility, and synergy of modeling and simulation throughout the DoD.

Degree of Maturity: J-MASS is in EMD with first product release which will be available for Air Force application. Five prototype builds preceded the first production release. The Air Force Research Laboratory (formerly Wright Laboratory – WL/AA) is providing technology insertion for long-lead items such as High Level Architecture compliance.

Potential Air Force Application Area(s)/Benefit to the Air Force: The Four Star M&S Summit vision is for a Joint Synthetic Battlespace--an integrated, common modeling and simulation environment that will be accessed by analysts, warfighters, developers, and testers supporting the range of Air Force tasks, from determining requirements through conducting operations. J-MASS was identified as the AF standard M&S system for the development, acquisition, and test and evaluation process. The J-MASS is an Air Force-directed program to develop and deliver a distributed, object-oriented, simulation architecture and system focused on the tactical level of war (mission and engagement simulations). The Joint standards (J-MASS, JWARS, JSIMS) and the systems that support them will enable interoperability and reusability of Air Force M&S tools across key communities and processes. The Joint standards serve as GOTS frameworks for the addition of third-party applications. These initiatives, coupled with ongoing improvements and standards, will bring the Air Force measurably closer to the objective of a common, integrated M&S system.

Major Players/Leaders Doing Research in this Technology Area:

William K. McQuay
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/AASE
Bldg 620, 2241 Avionics Cir, Rm N3-F22
Wright-Patterson AFB OH 45433
Phone: (513) 255-4511
E-mail: mcquaywk@aa.wpafb.af.mil

Dr Jerry Arnett
ASC/XRJ
Wright-Patterson AFB OH 45433

Vision of Your M&S Technology: J-MASS is an Air Force advanced simulation technology program that already has many of the characteristics for future M&S systems shown in table below. Considering user requirements, future J-MASS releases will move into other advanced technology areas.

Future M&S Characteristics & J-MASS Technology

M&S Characteristics	J-MASS Rel 3.0/a	Future Release
Open Systems Architecture	X	
Visual Paradigm	X	Enhancements
Object-based for Component Reuse	X	
Extensible Architecture (can use COTS)	X	Enhancements
Distributed Heterogeneous Network	X	Enhancements
Tool for Model Development	X	Enhancements
Multiple Language Support	C++, Ada83	
Object-oriented Database		X
Plug & Play	X	
Distributed Model Development	X	
Model Repository	X	Enhancements
Model Documentation Supports Reuse	X	
Integral VV&A Process	In Progress	
DIS Support	X	
HLA Compliant	In Progress	

Name, Address, Phone Number, and E-mail of Person Providing This Input:

William K. McQuay
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/AASE
Bldg 620, 2241 Avionics Cir, Rm N3-F22
Wright-Patterson AFB OH 45433
Phone: (513) 255-4511
E-mail: mcquaywk@aa.wpafb.af.mil

Enabling Technology #85: Desktop M&S

Brief Description of the Technology Area: The traditional simulations have used mainframes, minicomputers, and scientific/engineering workstations. The rapid advance of computer technology has brought much of this computational horsepower to the desktop PC. Desktop M&S is the application of joint simulation standards to a modeling system that will operate on an MS Windows NT environment and interoperate with simulations executing on workstations, computational servers, and other processors. It brings M&S to the same platform as our word processors and e-mail access. Desktop M&S addresses the development, configuration, execution, and post-execution processing of simulation results. DoD acquisition reform in DoD Directive 5000.1 and similar policies has increased the emphasis on M&S throughout the acquisition process. DoD is moving toward a Simulation-Based Acquisition system supplemented with extensive simulation in training and operations. It is critical that M&S now be a tool on every desktop for the engineer, analyst, trainer, logistician, and warfighter. Initially, Desktop M&S will address constructive modeling and then proceed to virtual and live interfaces. It will deal with all functional areas in the Air Force enterprise.

Degree of Maturity: Initial PC-based prototypes are underway. The basic technology on a PC is used in non-M&S areas today, and the M&S technology is already available on UNIX workstations. M&S technology must be moved into the PC arena. Technology will be mature in 2-3 years. The ongoing efforts need to be accelerated so that robust capability is available within 12-18 months.

Potential Air Force Application Area(s)/Benefit to the Air Force: The Four Star M&S Summit vision is for a Joint Synthetic Battlespace--an integrated, common modeling and simulation environment that will be accessed by analysts, warfighters, developers, and testers supporting the range of Air Force tasks, from determining requirements through conducting operations. To implement this vision, the synthetic battlespace must be brought to the desktop to interact with the users throughout Air Force.

Major Players/Leaders Doing Research in this Technology Area:

William K. McQuay
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/AASE
Bldg 620, 2241 Avionics Cir, Rm N3-F22
Wright-Patterson AFB OH 45433
Phone: (513) 255-4511
E-mail: mcquaywk@aa.wpafb.af.mil

SAIC
EC M&S Division
1321 Research Park Drive
Beavercreek OH 45432

Spectra Research Inc.
7071 Corporate Way, Suite 108
Dayton OH 45459

Vision of Your M&S Technology: Desktop M&S will become as pervasive a tool as PC spreadsheets are today. The Joint M&S standards will be used in conjunction with available COTS products (Word, Excel, MatLab, MathCad etc.) that already exist on the PC. M&S will be used daily on the desktop for analysis and decision making throughout DoD. The Visual Paradigm--visual development of models, visual data configuration, and visualization of output results--will be the normal. Ongoing Small Business Innovation Research (SBIR), Independent Research and Development (IR&D), and government research efforts address all of these areas. An application technology effort needs to bring them together on the PC.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

William K. McQuay
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/AASE
Bldg 620, 2241 Avionics Cir, Rm N3-F22
Wright-Patterson AFB OH 45433
Phone: (513) 255-4511
E-mail: mcquaywk@aa.wpafb.af.mil

Enabling Technology #86: Collaborative Virtual Prototyping

Brief Description of the Technology Area: Collaborative Virtual Prototyping (CVP) is the application of advanced information systems technology in design, modeling, simulation, analysis, manufacturing, testing, and logistics to support life cycle development of a system in a geographically distributed electronic environment. It supports constructive, virtual, and live simulation across all of the acquisition process. It is a key enabling technology to meet the Four Star M&S Summit vision of a Joint Synthetic Battlespace for the acquisition domain. CVP is a key aspect of a Collaborative Engineering Environment that enables all members of the product team to capitalize on each member's specific capabilities and assets. Collaborative Engineering eliminates the distances between facilities and creates a new distributed capability. M&S technology is a critical ingredient for the engineering environment.

Degree of Maturity: Some capabilities available now with additions over the next 2-4 years. Initial capability can be put into place today and enhanced with technology insertion.

Potential Air Force Application Area(s)/Benefit to the Air Force: The current DoD and Air Force vision is common M&S to support technology assessment, system upgrade, prototype and full-scale development, and force structuring. Changes in simulation technology now allow the creation of virtual prototypes of conceptual hardware systems in advance of when actual hardware could be built. DoD Directive 5000.1, "Defense Acquisition," requires virtual prototypes of all systems under development. CVP is the enabling technology for complying with the new 5000 series. Starting in the Laboratory, the digital model becomes more detailed as the conceptual system and design evolve and as the hardware technology moves from breadboard to brassboard to flyable prototype. The digital model is then transitioned with the hardware technology from the laboratory to the product center for further engineering and manufacturing development into a deployable system.

The Air Force Research Laboratory (formerly Wright Laboratory - WL/AA) demonstrated the advantages of transitioning a virtual prototype of avionics technology to the customer with the ASTE flare technology delivered to ASC/LN.

Major Players/Leaders Doing Research in this Technology Area

William K. McQuay
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/AASE
Bldg 620, 2241 Avionics Cir, Rm N3-F22
Wright-Patterson AFB OH 45433
Phone: (513) 255-4511
E-mail: mcquaywk@aa.wpafb.af.mil

Gary Jones
Simulation Based Design
DARPA/ITO

Michael K. Murray
Air Force Research Laboratory
(formerly Wright Laboratory) WL/AAJW
Wright Patterson AFB OH 45433
Phone: (513) 255-4174
E-mail: murraymk@aa.wpafb.af.mil

Brian Clayton
SAIC
101 Woodman Drive
Suite 103
Dayton OH 45431

Jerry Dague
SAIC
101 Woodman Drive
Suite 103
Dayton OH 45431

George Vogel, Air Force Research Lab
(formerly Wright Lab) - WL/AAJW
Wright Patterson AFB OH 45433
Phone: (513) 255-7102

Daniel P. Schiavone, Vance Saunders, Larry Jobson, Mark Speed
Ball Aerospace and Technologies Corp.
2875 Presidential Dr Suite 180
Fairborn OH 45324
Phone: (513) 320-4060
Fax: (513) 429-1687
E-mail: dschiavone@ball.com

Vision of Your M&S Technology: The vision is for an open-system approach based on the AF common M&S architecture with COTS products support as needed by individual organizations. The underlying core modeling system is based on joint standards such as J-MASS, JWARS, and JSIMS. The vision is included in the AF M&S Roadmap and requirement for virtual prototyping in DoDD 5000.1. Collaborative Virtual Prototyping as part of a Collaborative Engineering Environment will support the DoD vision of Simulation- Based Acquisition across the full life cycle from S&T in the labs through engineering development into manufacturing onto sustainment and then disposal.

Comments: AFMC/ST should accelerate the use of virtual prototyping in the laboratories based on joint standards consistent with the Four Star M&S Summit.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

William K. McQuay
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/AASE
Bldg 620, 2241 Avionics Cir, Rm N3-F22
Wright-Patterson AFB OH 45433
Phone: (513) 255-4511
E-mail: mcquaywk@aa.wpafb.af.mil

Enabling Technology #87: Khoros -The Visual Programming Environment

Brief Description of the Technology Area: Khoros contains software development tools and programming services which support all aspects of developing new engineering and scientific applications. The Khoros software development system can be used for software integration where existing programs are brought together into a consistent, standardized, and coherent environment. Khoros is a visual programming environment and Cantata is a graphically expressed, data flow, visual language that provides a visual programming environment within the Khoros system. Data flow is a "naturally visible" approach in which a visual program is described as a direct graph, where each node represents an operator or function and each directed arc represents a path over which data flows. The purpose in providing a visual language interface to programs included in the Khoros system is to increase productivity of researchers and application developers. By providing a more natural environment similar to block diagrams already familiar to practitioners in the field, the visual language provides support to both novice and experienced programmers.

Degree of Maturity: Khoros is in its second update, Khoros 2.0, with another update Khoros 2.1 scheduled soon. Several Air Force Research Laboratory (AFRL) modeling and simulation programs are unitizing the Khoros environment. The Integrated Precision SAR targeting simulation being developed in AFRL (WL/AAMR) has selected Khoros 2.0 as its development environment.

Potential Air Force Application Area(s)/Benefit to the Air Force: Insertion of this technology would provide great benefits to the Air Force in virtually every application area. As simulation increases, the level of data flow and memory storage as well as computational intensive task, High Performance Computers (HPC) will be required. Khoros can possibly support the transition from Sun-like platforms to HPCs.

Major Players/Leaders Doing Research in this Technology Area:

Khoral Research Inc. (KRI)
6001 Indian School Rd NE, Ste 200
Albuquerque NM 87110
Phone: (505) 837-6500
Fax: (505) 881-3842
E-mail: khoros-request@khoros.unm.edu

DARPA/ISO
Dr Mark Davis
3701 N. Fairfax Dr
Arlington VA 22208-1714
Phone: (513) 429-5056

Sverdrup Technology Inc.
Donnie Cates
4200 Col Glenn Hwy Ste 500
Beavercreek OH 45431

Vision of Your M&S Technology: Information on Khoros can be obtained from Khoral Research Inc.'s WWWsite: http://www.khoros.unm.edu/

Comments: The Combat Information Division has numerous amounts of information on Khoros. AAMR has just begun to work with the Khoros environment.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Ms Jacqueline Toussaint, Air Force Research Laboratory (formerly Wright Laboratory) - AAMR
2241 Avionics Circle, Rm N3-Y6, Wright-Patterson AFB OH 45433-7333

Enabling Technology #88: Resolution and Validation Manager

Brief Description of the Technology Area: Resolution Management is the management of multiple level-of-detail simulations, players, and assets. With current DoD spending levels at the lowest in decades, more "integrate old" versus "build new" approaches are being taken to fulfill new requirements in the M&S arena. Difficulties with this approach are the problems associated with the different levels of detail (resolution, granularity, or fidelity) of the simulations and models. The problem does not just include translation from one-model data types to another, but also the management of "when" the algorithms of one model should be utilized versus another model. "How" the data is translated, and "when" is the transition point, are best handled by an umpire instead of any model in particular. This umpire is the management software required to model, translate, and decide on resolution changes. This enabling technology allows all levels of the technical and analytical M&S community to interact. The Resolution Manager can also include checks on the validated range over which the model can be used. The Resolution Manager can flag when the model is being used outside of its validated and accredited region. This technology is applicable to the constructive, virtual, and live simulations.

Degree of Maturity: While a Resolution Manager is not currently available off-the-shelf, a prototype demonstration was developed for the Air Force Research Laboratory (formerly Wright Laboratory) WL/AASE, for the management of resolution between mission-level and engagement-level simulations. Using the missile flyout models within the engagement-level simulation enhanced the mission-level simulation. As the engagement-level simulation executed the flyout and modeled countermeasure effectiveness, the intermediate results were continuously being used to update parameters in the mission-level simulation. This prototype successfully demonstrated the ability to increase the level of fidelity of modeling without significant modifications to models.

Potential Air Force Application Area(s)/Benefit to the Air Force: This technology can be used in a wide variety of USAF applications. Using the Joint M&S standards, such as J-MASS, during execution of a simulation in order to reduce runtime, users may want to move from higher level models to more detailed models at the appropriate time, such as near the endgame of an engagement. The Resolution Manager can appropriately make this switchover and use a higher fidelity model when appropriate. In current legacy simulations, a user with a requirement of enhanced fidelity modeling could take advantage of this concept. Instead of costly modifications to develop source code for higher level modeling in current simulations, or completely developing new applications, integrating functionality from other assets has huge potential savings.

Major Players/Leaders Doing Research in this Technology Area:

Daniel P. Schiavone, John Prikkel, James Hooker
Ball Aerospace and Technologies Corp.
2875 Presidential Dr, Suite 180
Fairborn OH 45324
Phone: (513) 320-4060 Fax: (513) 429-1687
E-mail: dschiavone@ball.com

Mr Ronald Clericus
QuesTech Inc.
5717 Huberville Avenue
Dayton OH 45431
Phone: (513) 476-7248

Ms Marilyn Shaw
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/AASE-2
Wright-Patterson AFB OH 45433
Phone: (513) 255-4264

Vision of Your M&S Technology: A Resolution and Validation Manager (RVM) is a significant capability for the Verification, Validation, and Accreditation process for simulations. VV&A is a continuous process that can be costly and difficult to conduct and maintain. RVM can partially automate the validation by checking on the usage of models within their validated range of operation. The RVM would use an electronic validation document as input on the appropriate range of operation for the simulation. RVM also addresses the aggregation/de-aggregation issue during runtime. RVM can provide a methodology to move back and forth with variable resolution models whenever appropriate during execution. The prototypes are in development with the Air Force Research Laboratory (WL/AA). RVM efforts should be accelerated by AFMC/ST.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

William K. McQuay
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/AASE
Bldg 620, 2241 Avionics Cir, Rm N3-F22
Wright-Patterson AFB OH 45433
Phone: (513) 255-4511
E-mail: mcquaywk@aa.wpafb.af.mil

Enabling Technology #89: Exercise Management

Brief Description of the Technology Area: Distributed M&S applications dealing in "hard" real-time world (MITL, HITL, Live, etc..) have strict timing requirements. These requirements are compounded by difficulties and timing necessary in managing the assets. Exercise managers are being developed to manage not only the hardware assets (processors, bandwidth, etc.) but also the virtual worlds created in the distributed modeling environment. The M&S community recognizes that a test manager (human) cannot effectively manage the execution environment without assistance of a software tool that consistently monitors the test environment, communicates the environment to the test director, accepts commands from the director, and carries out detailed simulation interaction involved in ensuring the command directive. They are recognizing this with the evolving High Level Architecture (HLA) definition that includes Exercise Managers, Directors, Simulation Controllers, Middleware, etc.

Degree of Maturity: While this technology is currently evolving, there is a large amount of interest driving many development efforts. The non-DoD community established several COTS packages that can be built upon for USAF applications. In addition, several DoD projects have/are developing tools/prototypes/etc., including the Electronic Combat Integrated Test (ECIT) Facility, DoD High Level Architecture, and DARPA's Simulation-Based Design, just to name a few. With continued funding, application is in 2-4 years.

Potential Air Force Application Area(s)/Benefit to the Air Force: The next step in real-time M&S is to expand the capabilities and products of distributed applications past the training community and into the engineering and T&E facilities. This can only be achieved by assuring real-time performance. The huge cost benefits alone of detailed engineering before the development of a new system or procurement has already been demonstrated.

Major Players/Leaders Doing Research in this Technology Area:

Larry Jobson, Daniel P. Schiavone, Mark Speed, Vance Saunders
Ball Aerospace and Technologies Corp.
2875 Presidential Dr, Suite 180
Fairborn OH 45324
Phone: (513) 320-4060 Fax: (513) 429-1687
E-mail: dschiavone@ball.com

Vision of Your M&S Technology: To allow distributed real-time assets to interact in a seamless environment.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Capt Mike Lightner, Air Force Research Laboratory (formerly Wright Laboratory) - WL/AASE
Bldg 620, 2241 Avionics Cir, Rm N3-F22, Wright-Patterson AFB OH 45433
Phone: (513) 255-4511 E-mail: lightngm@aa.wpafb.af.mil

Enabling Technology #90: J-MASS Extensions For DoD HLA Interoperability

Brief Description of the Technology Area: This technology will allow the Joint Modeling and Simulation System (J-MASS), which is the AF standard M&S system for the development, acquisition, and test and evaluation process, to easily adopt the DoD High Level Architecture (HLA), the standard DoD communications architecture. When this technology is fully implemented, J-MASS simulations will be available for inclusion in HLA Federations across the DoD. Extensions of the J-MASS architecture simulation engine are required to allow J-MASS engineering models at the unit, platform, and subsystem levels to easily interoperate with simulations throughout the DoD. This technology involves extensions/modifications to the J-MASS port objects structure and the player query functions. In addition, appropriate adaptations of the time management and spatial systems in J-MASS will be extended for use when J-MASS simulations play in HLA Federation exercises. There is a possibility of the HLA RunTime Infrastructure (RTI) becoming the J-MASS communications backplane.

Degree of Maturity: Technology is in its infant stages. It is being defined and evolved via the prototyping efforts for HLA. As the HLA itself is evolving, it is anticipated this technology can be matured over the next 2-3 years.

Potential Air Force Application Area(s)/Benefit to the Air Force: All Air Force M&S systems must comply with the DoD High Level Architecture, with development of plans to do so required in second quarter of FY97. This technology will bring the AF standard M&S System (J-MASS) in line with the HLA and make it possible for J-MASS simulations to comply with the HLA.

Major Players/Leaders Doing Research in this Technology Area:

Capt Mike Lightner
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/AASE
Bldg 620, 2241 Avionics Cir, Rm N3-F22
Wright-Patterson AFB OH 45433
Phone: (513) 255-4511
E-mail: lightngm@aa.wpafb.af.mil

SAIC
EC M&S Division
1321 Research Park Drive
Beavercreek OH 45432

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Capt Mike Lightner
Same as above

Enabling Technology #91: Automated J-MASS Tools for DoD HLA-Compliant Simulation Development

Brief Description of the Technology Area: This technology will create automated DoD High Level Architecture (HLA) simulation development tools for use in the Joint Modeling and Simulation System (J-MASS). When this technology is fully implemented, these J-MASS tools will be employed to automatically make J-MASS simulations HLA compliant. Areas where such tools will be developed include the visual component development tools, code generators, J-MASS team builders, simulation object model capture tools, etc. With such tools, J-MASS simulation developers will be able to comply with the HLA mandate without major effect to normal modeling efforts.

Degree of Maturity: Technology is in its infant stages. It is being defined and evolved via the prototyping efforts for HLA. As the HLA itself is evolving, it is anticipated this technology can be matured over the next 2-3 years.

Potential Air Force Application Area(s)/Benefit to the Air Force: In accordance with DOD Directive 5000.59P, all Air Force M&S systems must comply with the DoD High Level Architecture, with development of plans to do so required in second quarter of FY97. This technology will bring the AF standard M&S System (J-MASS) in line with the HLA and make it possible for J-MASS simulations to comply with the HLA.

Major Players/Leaders Doing Research in this Technology Area:

Capt Mike Lightner
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/AASE
Bldg 620, 2241 Avionics Cir, Rm N3-F22
Wright-Patterson AFB OH 45433
Phone: (513) 255-4511
E-mail: lightngm@aa.wpafb.af.mil

SAIC
EC M&S Division
1321 Research Park Drive
Beavercreek OH 45432

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Capt Mike Lightner
Same as above

Enabling Technology #92: IRCM Modeling

Brief Description of the Technology Area: Technology is needed that would allow modeling of missile systems by which you take a picture of the schematics and then the system would automatically create validated code. The code must be available in the different fidelities that the user would select. Code must be capable of running in real time.

Degree of Maturity: Currently, the schematics have to be converted to various transfer functions and then the code is generated. Maturity could be reached in 4 to 5 years.

Potential Air Force Application Area(s)/Benefit to the Air Force: Benefit to the Air Force would allow the investigation of foreign missiles and their performance against US countermeasure systems. As the systems change, the modeling aspect would always be current.

Major Players/Leaders Doing Research in this Technology Area:

Major players include myself, Dr George Vogel, Ed Huber, Brian Clayton, Dave Miller, and others that work in the DIME Lab, Avionics Directorate, Wright Laboratory (currently the Air Force Research Laboratory).

Vision of Your M&S Technology: A specific vision is "an easier way to model threat systems."

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Michael K. Murray
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/AAJW
Wright-Patterson AFB OH 45433
Phone: (513) 255-4174
E-mail: murraymk@aa.wpafb.af.mil

Enabling Technology #93: Modeling the Variability of IR Threat Systems

Brief Description of the Technology Area: Technology is needed where the variability of threat systems can be represented in digital models. As the threat systems are investigated, it becomes apparent that they do not all behave in the same way. A method is needed whereby the variation from threat to threat, as well as the variations in the different versions of the same type of threat, needs to be evaluated.

Degree of Maturity: Currently, no work is being done.

Potential Air Force Application Area(s)/Benefit to the Air Force: Knowing how the variations of the missiles produce the differences in their performance may help in the development of the countermeasures.

Major Players/Leaders Doing Research in this Technology Area:

Myself, Dr George Vogel, Ed Huber, Dave Miller, Brian Clayton, and others.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Michael K. Murray
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/AAJW
Wright-Patterson AFB OH 45433

Enabling Technology #94: Advanced Modeling Methods

Brief Description of the Technology Area: An advanced modeling methodology is being developed to increase productivity using commercial off-the-shelf tools such as MAT LAB (analysis, model development, and service code operation), FrameMaker (documentation), and MathCAD (symbolic Math). The methodology essentially replaces the often overwhelming code generation effort with autocoded modules, and provides resources to be used for documentation and checkout.

Degree of Maturity: The methodology has evolved during the past two years, creating two detailed, circuit-level models. Source code integration in C and C++ is being developed. Additional research is required to resolve issues related to integration into larger and multiple-platform simulations.

Potential Air Force Application Area(s) Benefit to the Air Force: Methodology has application in virtually every Model Development Area which uses system diagrams such as those that might be in a Threat Document.

Major Players/Leaders Doing Research in this Technology Area:

Brian Clayton	Jerry Dague	George Vogel, Air Force Research Lab
SAIC	SAIC	(formerly Wright Lab) - WL/AAJW
101 Woodman Dr	101 Woodman Dr	Wright-Patterson AFB OH 45433
Suite 103	Suite 103	Phone: (513) 255-7102
Dayton, OH 45431	Dayton, OH 45431	

Vision of Your M&S Technology: The methodology has already demonstrated:

- Rapid prototyping of systems
- Autogenerated code using MATRIXx or MATLAB
- Documentation for validation
- Ease of modification and integration

Based on my background, a very high percentage of a modeling effort can be consumed by the labor-intensive tasks of coding and debugging. Automated methods have been demonstrated to remove this task or reduce it to a minimum. Also, concurrent documentation is now much less painful and can be kept at an engineering level.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Brian L. Clayton, Address as above
E-mail: bclayton@erinet.com

Enabling Technology #95: Thermal Simulations using the COYOTE Computer Code

Brief Description of the Technology Area: COYOTE is a Galerkin finite element computer code for simulating complex, coupled, heat transfer problems on both serial and parallel computers. The development of this code is motivated by the need to simulate large, complex problems with coupled physics specific to applications of interest to the Department of Energy, Sandia National Laboratories, and our customers within the defense community. COYOTE presently models:

- non-linear, transient, heat conduction in reactive and non-reactive materials
- enclosure radiation in multiple enclosures (both partial and complete enclosures)
- thermal contact conductance through material interfaces and joints
- Eulerian and Lagrangian material motion
- birth and death of elements for material addition and decomposition/removal
- constant, tabular, and user-defined material properties, boundary conditions, and chemical reactions and reaction rates

To simulate coupled-physics problems, COYOTE readily couples with several other Sandia computer codes; JAS for quasistatics and TORO for electromagnetics, using a message-passing scheme.

Degree of Maturity: Over the last several years, an effort to increase the capabilities of COYOTE has been undertaken. COYOTE is a "mature" code for simulating basic thermal problems. In terms of new capabilities, it is in a "growth" phase. Research and development are ongoing to improve computational capabilities, to accommodate large problems, and to port the code to parallel architectures. Examples of new capabilities under consideration are aerodynamic heating and ablation using a moving mesh approach, participating media radiative transfer, spectral and specular radiative transfer, and multiphysics code-to-code coupling. The migration to parallel computing platforms will require several computational issues to be addressed. These include mesh decomposition, contact surface detection and conductance implementation, view factors computations, and enclosure radiation solution. Improvements in the fundamental data structures within COYOTE will provide dynamic mesh topologies. This capability can be applied to future problems involving decomposing materials and solution adaptive methods.

Potential Air Force Application Areas: The computational capabilities within COYOTE can be applied to the design and analysis of a wide variety of thermally dominated, multiphysics problems. The thermal chemical coupling in COYOTE is applicable to many military applications involving the safety and security of devices containing reactive energetic materials. The message-passing coupling with other mechanics codes provides capabilities for analyzing safety issues related to crash-and-burn accident scenarios and other thermal-chemical mechanical problems. Aerodynamic hearing and heat shield ablation capabilities can be applied to the thermal analysis of re-entry vehicles. In an aeroheating application, COYOTE can be used to predict the thermal response of internal components of weapon systems as well as the response of the exterior structure. Thermal analysis of satellites and components can also be performed with this code.

Major Players/Leaders in this Technology Area: The COYOTE development team is David Gartling, Roy Hogan, Mike Glass, Dave Kuntz, and Randy Lober of Sandia National Laboratories. Other computer codes for simulating thermal problems are PATRAN/P-THERMAL, SINDA, and codes from various software vendors.

Comments: Both Theory and User's Manuals for COYOTE are available on the COYOTE Home Page at www.cfd.sandia.gov/docs/coyote/coyote-welcome.html. Postscript files of the manuals are also available for downloading.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Roy Hogan
Thermal Sciences Department
Sandia National Laboratories
P.O. Box 5800, MS-0835
Albuquerque NM 87185-0835

Enabling Technology #96: Fire Modeling and Simulation

Brief Description of the Technology Area: Fires (and their consequences) often pose a major threat to engineered systems as well as to people. The goals of this research and development effort is to provide a scientific basis for the development of validated computational tools (software) for the modeling and simulation of large-scale (real-scale) fires and their effect on nearby systems. While computational tools form the main objective of the research and development, the program is a tightly integrated triad of computational tools, phenomenological investigation, and experimentation (including development of advanced diagnostics for real-scale fires).

A wide spectrum of research efforts is underway to support development of a broad range of computational fire tools. These tools range from very detailed (high fidelity) field models to more narrowly focused simulators that can be used in design and risk assessment applications. The spectrum of research efforts spans a wide range, including (for example): fuel dispersion, combustion modeling, large-eddy simulations, advanced diagnostics for soot, thermal radiation algorithms, solid material decomposition physics, and massively parallel computer implementations (driven by the DOE Accelerated Strategic Computing Initiative).

Degree of Maturity: Whereas combustion processes generally involve user control of some parameter(s) (such as fuel flow rate of air injection), fires represent a natural balance point between fuel, air, and energy. This results in a tight coupling of the physical phenomena, and hence tight coupling of the governing equations. The difficulty in developing appropriate models and solution algorithms for these tightly coupled nonlinear phenomena has caused fire science to lag far behind combustion science.

Over the past three years, significant progress has been made. The developing of a fire field model (Computational Fluid Dynamics-type model) which includes the combustion process, soot production, and thermal radiation transport has resulted in a powerful tool for the modeling and simulation of large-scale fires in real-world applications. This capability has served as a basis for: (a) the development of simulators for risk assessment calculations, (b) a design tool for development of experiments and experimental facilities, (c) a research tool for investigation of fire physics, and (d) an applications tool for specific problem solving.

Current work is focused on improving the fidelity of existing submodels (combustion, soot, fuel pool response), validation against large-scale experimental data (including advanced diagnostics development and generation of the data), development of suppression submodels, and conversion to a massively parallel computer architecture.

Potential Air Force Application Area(s)/Benefit to the Air Force: There are many foreseeable applications of the fire modeling and simulation technology described above which could be of benefit to the Air Force. For example, these computational fire tools have already been used (or are currently being used) to provide insight and obtain results for the following problems. Fuel fire effects on weapon systems and fuselages (resulting from a crash-and-burn scenario), enclosure fire effects on aircraft and weapon systems in hardened aircraft shelters, and fires in engine nacelles.

We have recently initiated a program with Wright-Patterson AFB to begin using these tools for the investigation of engine nacelle fire suppression. It may be of future interest to the Air Force to also use these tools to investigate the effect of enemy hits on an aircraft engine nacelle, and what the resulting consequences would be. Such information could be interfaced into pilot training simulators for combat situations.

These fire modeling and simulation tools could also be used to investigate the effect of fires on conventional and nuclear weapons systems of interest to the Air Force. They could be incorporated in the design process for a weapon system (or delivery or storage system), or they could be used to assess the risk inherent to an existing design. Further development and application of these tools could also yield insight into the best methods for extinguishing in-flight fires aboard aircraft, as well as ground-based fires involving aircraft.

In the longer term, with the advent of massively parallel computers and algorithms, these computational fire tools could be used to provide an interactive (real-time) simulator for fire brigade emergency response training.

Major Players/Leaders Doing Research in this Technology Area:

Sandia National Laboratories Fire Science and Technology Team
SINTEF Applied Thermodynamics (Trondheim, Norway)

Comments: Additional information regarding the technical efforts discussed above are available upon request from the point of contact listed below:

Point of Contact:

Sandia National Laboratories
Jaime Moya, MS 0865, Org. 9735
P.O. Box 5800
Albuquerque NM 87185-0865
Phone: (505) 844-7955
Fax: (505) 844-7858
E-mail: JLMOYA@sandia.gov

Sandia National Laboratories
Carl W. Peterson, Jr.
MS 0836, Org. 9116
P.O. Box 5800
Albuquerque NM 87185-0836
Phone: (505) 844-6775
Fax: (505) 844-8423
E-mail: CWPETER@sandia.gov

Enabling Technology #97: MuSE (Multidimensional, User-oriented Synthetic Environment)

Brief Description of the Technology Area: MuSE provides a common environment for data fusion and extremely rapid human interpretation of such data across multiple, simultaneously presented data sets. The advantage of MuSE over other "virtual reality"-based technologies is that it is founded on exploitation of human cognitive processes. The brain's parallel processing capability in formatting data for analysis is an important technical underpinning in matching computer to human capabilities as opposed to current matching of the human to the computer. Specifically, MuSE data presentation methodologies are subordinated to human sensory reception (e.g., visualization) and associated cognitive strengths as the primary mode of information depiction. Pattern recognition, trend analysis, and anomaly detection--three prominent human cognitive attributes--form the basis for data presentation methodologies.

Degree of Maturity: MuSE has been in development and testing for more than four years at the DOE Sandia Laboratory. It has already been employed in a wide range of applications. They include: Manufacturing process simulation; CAD analysis and operation; Medical examination and preparation for tumor operation; Data analysis of voluminous transportation data sets; Command and control situational analysis; and, Sensor data fusion. Application-oriented R&D to meet specific customer needs is already underway with the US Navy, NASA, DARPA, DOT and commercial companies in the fields of manufacturing and energy.

Potential Air Force Application Area(s)/Benefit to the Air Force: Areas of potential Air Force application of MuSE include practically all AF activities, ranging from acquisition (system design/manufacturing processes) through training to combat operations. Training: The Navy project involving the presentation and interpretation of sonar data to operators provided strong indication of an acceleration of the learning process by two orders of magnitude. That equates to compressing a three-year learning process into two weeks. Operations: Massive amounts of dissimilar data (overhead imaging, JSTARS, AWACS, Humint, et al) can be interpreted and integrated to provide theater-wide situational awareness—an especially fertile area for future application research and development. Acquisition: Reviewing new weapon system designs/functions prior to even building a prototype provides promise of minimum development time at minimum cost. Maintenance of Industrial/Tech Base: Review of manufacturing processes prior to implementing on production lines holds the same cost minimization potential.

Major Players/Leaders Doing Research in this Technology Area:

Dr Creve Maples
MuSE Technologies, Inc.
1601 Randolph Rd. SE, Suite 20
Albuquerque, NM 87106
Phone: (505)843-6873
Fax: (505)766-9123
E-mail: info@musetech.com

Vision of Your M&S Technology: MuSE technology has potential that may prove profound in its impact on:

- Weapon System Acquisition Costs ($$$s and time to field new system)
- Cost of Training (100X shorter) for operators of systems involving massive data fusion and/or interpretation
- Situational Awareness during Combat Operations maximizes the value of every data collection investment (e.g. JSTARS, satellite, or humint)
- Supports Tech Base upgrade at minimum cost through preview of processes and/or proposed production equipment

More rapid and complete understanding of information is achieved by tailoring data presentation and interaction to the human sensory and associated cognitive processes. Another major benefit is independence of data processing from communication methods.

Comments: See:

- Washington Post TECHREPORT
- Manufacturing Engineering Magazine/Nov 94
- USCAR (Council for Automotive Research)/Fall 95
- ProE Magazine (PTC Mkt)/Oct 94
- Computer Graphics World/Jul 95
- IJCAI-95/Proceedings, 14th Intl Joint Conference on Artificial Intelligence
- VR World Magazine/Aug 95
- Technology Transfer Week/Nov 95

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Dr Creve Maples
MuSE Technologies, Inc.
1601 Randolph Rd SE, Suite 210
Albuquerque NM 87106
Phone: (505) 843-6873
Fax: (505) 766-9123
E-mail: info@musetech.com

Enabling Technology #98: Hearing Functional Evaluation

Brief Description of Technology: Otoacoustic emissions (OAEs) are low-level sounds produced by the inner ear as part of the normal hearing process. There is great potential in using reliably measured OAE to provide a quick, inexpensive and nonintrusive assessment of hearing function, and in the detection of early temporal damage to hearing function. To further explore this potential, an advanced fuzzy logic filtering technique-based OAE measurement approach has been investigated. The results show that integrating inexact human experts and rigorous mathematical filters have the greatest potential in removing noise and uncertainties in the data to provide reliable and quick measurement. Auditory Brainstem Response (ABR) measures central hearing and neurological functions by monitoring tiny scalp electric currents from a subject listening to clicks. The OAE test evaluates peripheral functions while the ABR can provide a central nervous system functional assessment. Combining the two measures could provide a very promising diagnostic and monitoring tool.

Degree of Maturity: OAE and ABR are currently the most widely used test tools for objective hearing evaluation. A reliable test requires very quiet testing conditions (i.e., a soundproof room). This is a significant limitation on their applications. Current efforts at CMI are focused on alleviating this limitation, and on integrating the two biological signal processing systems into a single readout device.

Potential Air Force Application: Normal hearing functions are vital for everyone. Unlike most of the civilian population, military personnel must perform their duties at the risk of being exposed to hazards, such as high noise levels. Furthermore, good hearing is critical for military personnel in accomplishing their mission. This technology will provide a reliable and objective tool for full hearing evaluation and should detect any early temporal damage. Early intervention can assist in preventing any minor damage from progressing to chronic hearing impairment. Future simulators could include feedback loops to assess hearing, particularly if information assimilation through the auditory system is critical to the tasks/operations being simulated.

Major Players/Leaders Doing Research in this Technology Area Hearing assessment is an important area of investigation in the Aerospace Medicine Directorate of the Armstrong Laboratory (currently the Air Force Research Laboratory), Human Systems Center, Brooks AFB, TX (Lt Col Allen, AL/AOC, DSN 240-2177). CMI is currently investigating this area as part of the Small Business Innovative Research Program. Other players include Virtual Corporation and possibly the entertainment industry.

Elaine Mendoza, President and CEO
Conceptual MindWorks, Inc. (CMI)
4318 Woodcock Drive, Suite 210
San Antonio TX 78228-1316
Phone: (210) 737-0777
E-mail: emendoza@mail.teamcmi.com

Jun Zhou, Ph.D., Senior Research Engineer
jun@mail.teamcmi.com

Enabling Technology #99: Cognitive Modeling

Brief Description of the Technology Area: This technology involves the modeling of human cognition (the way we think). This can include decision making, knowledge we have gained, memory fading, schemas (complex representations and associations with objects we know) we form, and how they interact. The tools used for cognitive modeling include: neural networks, expert systems, and probabilistic systems such as Bayesian and Markov networks.

Degree of Maturity: Variable. Expert system technology is fairly mature. Some parts of it are probably more mature than others; for example, the military has conducted psychological testing for many years. Expert systems are more mature than neural networks. Neural networks offer a new area of research that could provide a fresh approach to a long-standing research problem.

Potential Air Force Application: Potential uses include designing of improved working environments, predicting behavior under given circumstances, modeling computer/human and more general machine/human interactions, and improvement in the design of intelligent tutors. For example, currently, a new cognitive model and tutor/programming technique has to be developed for every new domain--a costly proposition. New authoring tools and expert systems could be made more general and flexible. Some of the emerging intelligent software techniques could be applied to significantly advance these areas of need. A significant factor in achieving these benefits would be bridging the knowledge/applications gap between cognitive psychologists and computer or neural network technology.

Major Players/Leaders Doing Research in this Technology Area: John R. Anderson, Wes Regian and Val Shute are well known in cognitive modeling. David Rummelhart, Hecht Nielssen, Steve Grossberg, and Karen Carpenter are all known internationally for neural networks. Some or all of these scientists perform research in the cognitive domain. The Air Force Office of Scientific Research (AFOSR) is a leading Air Force focal point for research in this area (DSN 240-8075).

Elaine Mendoza, President and CEO
Conceptual MindWorks, Inc. (CMI)
4318 Woodcock Drive, Suite 210
San Antonio TX 78228-1316
Phone: (210) 737-0777
E-mail: emendoza@mail.teamcmi.com

Tom Arnow, Senior Research Engineer
tom@mail.teamcmi.com

Enabling Technology #100: Portable, Neurological Function, Automated, Diagnostic Device

Brief Description of Technology Area: The envisioned product of this technology area is a portable diagnostic device consisting of evoked potential stimulation, recording, and analysis components. The device should be expected to provide rapid diagnoses of emergent neurologic conditions such as head trauma, spinal cord injury, and stroke, in order to expedite intervention during the initial patient contact prior to definitive treatment at a remote facility. Early intervention is likely to considerably reduce permanent morbidity and mortality of extremely common neurological diseases.

Degree of Maturity: This device is currently a Phase I Small Business Innovation Research project. A working prototype should be constructed in two years with continued research and development funding.

Potential Air Force Application: The envisioned device would provide considerable benefit to both military and civilian emergency medical care delivery. Permanent morbidity and mortality from neurological injury resulting from combat or training exercises are likely to be reduced by rapid diagnosis and intervention prior to, or during transport to, a definitive care center. In addition, nontraumatic conditions including stroke, which often is not accompanied by obvious physical symptoms, could similarly be rapidly diagnosed. Early intervention during a verified stroke is also likely to significantly improve the final outcome in affected individuals. This tool could also be used in Modeling and Simulation research. Feedback from individuals participating in simulator activity could be assessed for Central Nervous/Cognitive function. In addition to providing an objective measure of brain wave function from inputs acquired from the simulation in progress, the tool could be used to identify, verify, and enhance direct brain to aircraft/weapons control "circuits."

Major Players/Leaders Doing Research in this Technology Area: No other investigations involving development of a portable, neurological function, automated diagnostic device are known. Work in the use of hands-off or brain functional control is being conducted at the Air Force Research Laboratory (formerlyArmstrong Laboratory), Human Systems Center, Wright-Patterson AFB, OH. The contact is Dr Grant McMillan, AL/CF (DSN 785-3602).

Elaine Mendoza, President and CEO
Conceptual MindWorks, Inc. (CMI)
4318 Woodcock Drive, Suite 210
San Antonio TX 78228-1316
Phone: (210) 737-0777
E-mail: emendoza@mail.teamcmi.com

Tom McMurray, Senior Research Engineer
cmurray@mail.teamcmi.com

Enabling Technology #101: Multilevel and Cross-Resolution Modeling

Brief Description of the Technology: This research area addresses the significant problems of connecting models of different resolution as well as allowing multiple levels of resolution within the same model. Advances in this area are necessary to permit consistent connections between different models in the DIS and ADS world as well as creating consistent hierarchical families of models. Lack of attention to this issue has caused important difficulties in DIS and inconsistent results derived from models of differing resolution. (Tanks appear to aircraft to be underground or in the air because of inconsistent terrain resolution, making the tanks invulnerable to air-to-ground attacks, for example).

Degree of Maturity: Some results exist and new models under development should pay attention to this need for consistency by building in certain multiresolution features.

Potential Air Force Application Area(s)/Benefit to the Air Force: As illustrated above, inconsistent model connections or families of models can lead to analysis and training results that are biased in ways that do not show the true effects of airpower.

Major Players / Leaders Doing Research in this Technology Area: At the moment, DMSO has several projects underway to investigate this issue. Principal investigators are Dick Hillestad and Paul Davis at Rand, Ben Wise at SAIC, and Paul Reynolds (professor at a Washington area university).

Paul Davis
Rand Corp
Phone: (310) 393-0411
E-mail: Paul_Davis@rand.org

Comments: Several papers describing earlier research in this area can be found in Naval Research Logistics, Vol. 42, 1995.

Enabling Technology #102: Exploratory Modeling

Brief Description of the Technology Area: This technology area addresses how models are used rather than what is in the model. Exploratory modeling involves performing computational experiments using the increased computational power and storage available in networked workstations. The experiment tells us what the outcome would be if all the guesses we had to make in setting up the model turned out to be true. The guesses are not actually expected to all be predictive, but the knowledge that those assumptions lead to the observed outcome is new knowledge provided by the computational experiment. The available knowledge is viewed as being contained in the collection of all possible modeling experiments that are plausible given what we know. Analysis in this context is based on the discovery of computational experiments with key properties that support a credible argument for a decision. Exploratory modeling is different from traditional sensitivity testing. The goal of sensitivity analysis is to attach a variance estimate to the predictions of a model. Exploratory modeling searches for a viable basis for a policy decision in spite of the uncertainties and unpredictability of the problem. In effect, exploratory modeling looks for a question that can be answered, in spite of uncertainty or unpredictability, e.g., we might look for actions that should be taken now even though we don't know what will happen in the future.

Degree of Maturity: Exploratory modeling has been used at Rand for Global Climate analysis and theater/campaign analysis. Because models are used in nontraditional ways, alternative methods require some additional research. Additionally, other enabling technologies are necessary such as computational speed, large storage, computer graphics, and user interfaces to handle the large computational experiments and provide simple means for selecting, browsing, and visualizing results. One example is computer support to present multiple-dimensional graphs.

Potential Air Force Application Area(s)/Benefit to the Air Force: The biggest benefit is to better inform the decision making process. Currently, there is a great deal of emphasis improving the content of models by increasing both the scope and detail of what they represent. Our contention is that the problem with today's models is often not what is in them, but how they are (mis)used. Even if the models are improved in the future, if model use is not improved (such as the exploratory modeling approach), the Air Force will continue to have many of the same complaints about M&S and, more importantly, the ability of model-based analysis to influence the decision making process will continue to be at the same level of (in)effectivity.

Major Players/Leaders Doing Research in this Technology Area:

Steve Bankes
Rand Corp
Phone: (310) 393-0411
E-mail: Steven_Bankes@rand.org

Comments: Among other documents describing exploratory analysis in other context, a documented briefing on this technology area in an Air Force context will be published soon.

Enabling Technology #103: Designing Virtual/Live/Constructive Simulation Experiments

Brief Description of the Technology Area: Advanced distributed simulation (ADS) technologies has allowed analysts to use combinations of virtual, live, and constructive simulations in studies. ADS has the potential to address some of the most challenging aspects of combat simulation: human and live system performance, and high resolution, theater-level battles. However, analysts have been slow to embrace ADS. Why? Because, as with any new paradigm, ADS brings with it both a culture change and formidable analysis challenges; such as additional costs, reduced experimental control, and feasible sample sizes. Those analysts in the vanguard of designing combinations of virtual/live/constructive simulation experiments are struggling with how best to use the mixture of tools.

Degree of Maturity: Relatively new field. People have been doing uncoordinated efforts for the last few years.

Potential Air Force Application Area(s)/Benefit to the Air Force: Maturation and insertion of this technology would help in decision-making activities in system design, employment, acquisition, joint-employment, and force structure analysis.

Major Players/Leaders Doing Research in this Technology Area: Relatively new field. Key people working in this area include:

Will Brooks
US Army Materiel Systems Analysis Activity
Aberdeen Proving Ground MD 21005-5071
E-mail: wbrooks@arl.mil

LtCol Dennis Lester
Det 4, 505 CCEG
1655 First St, SE
Kirtland AFB NM 87117-5617
E-mail: LESTER@awcnet.eglin.af.mil

Dr Tom Lucas
Rand Corp
1700 Main Street
Santa Monica CA 90407-2138
E-mail: Tom_Lucas@rand.org

Bryson McCool
US Army TRAC-WSMR
White Sands Missile Range NM 88002-5502

Enabling Technology #104: Generalized Networks Algorithms (for object movement and object interactions)

Brief Description of the Technology Area: Many campaign simulations require ground and air forces to move along predefined corridors or pistons. Lateral or enveloping movements are seriously constrained if not impossible. Piston or even hexagonal models are just specific cases of a generalized network where freedom of movement is far less constrained. Moving to the generalized network also allows for the definition of defense and target regions, areas for sensor and communication coverage, and zones for restricted movement. The piston and hex networks were used to limit the processing overhead; however, using various preprocessing methods, the generalized network approach can be nearly as efficiently implemented.

Degree of Maturity: In recent years, advances in graph theory and network algorithms have advanced the state-of-the-art. Additional research is required, but these methods could be exploited today.

Potential Air Force Application Area(s)/Benefit to the Air Force: Many modeling activities that restrict aircraft movement to pistons or hexes can underestimate the flexibility of airpower and, hence, the warfighting contribution of the Air Force.

Major Players/Leaders Doing Research in this Technology Area:

Richard Hillestad
Rand Corp
Phone: (310) 393-0411
E-mail: Richard_Hillestad@rand.org

Louis Moore
Rand Corp
Phone: (310) 393-0411
E-mail: Louis_Moore@rand.org

Wayne Zandberg
S3I
Phone: (703) 684-8268
E-mail: s3i@interramp.com

Comments: Details of Rand's generalized network research can be found in DRR 575 AF/A, which was distributed to AF/XOM. This draft report will be released in final form as MR 388 AF/A by RAND.

Enabling Technology #105: Air Campaign Optimization

Brief Description of the Technology Area: This area attempts to find the "best" allocation of aircraft to missions and targets during the course of an air/land theater campaign. The optimization process considers action and reaction by performing a two-sided, "gamed" allocation of aircraft with constrained gradient search techniques. It is also used to allocate long-range fires. It is extremely important in the analysis of new capabilities because it helps to determine how they perform with "best use" and when an enemy can adapt to their use.

Degree of Maturity: Initial versions of this methodology were used in the 1980s in campaign analysis of cold war air campaigns. The methodology is available for use in campaign simulations.

Potential Air Force Application Area(s)/Benefit to the Air Force: This is directly applicable to the Air Force as noted above. Lack of use of "best use" in most current campaign models is a serious shortcoming of those models for analysis purposes. Without such a methodology, one is always left with the question of whether the Air Force and its capabilities were used to best effect.

Major Players/Leaders Doing Research in this Technology Area: Dick Hillestad at Rand and Leon Goodson have worked on similar imbedded optimization methodologies for campaign models.

Comments: A Rand report, DRR 575 AF/A, which was distributed to AF/XOM describes both the motivation for this approach and, in an appendix, describes the actual algorithm. This report will be released as MR 388 AF/A by Rand.

Enabling Technology #106: Genetic Algorithms

Brief Description of the Technology Area: Genetic algorithms can be used to solve optimization problems, particularly complicated nonlinear problems. We have had success using them to automate decision processes embedded in simulations. This approach iteratively improves the decision by search for preferred solutions until only marginal improvement is repeatedly achieved or until the amount of time available to perform the computation expires. Decisions that can involve genetic algorithms include force/mix or resource allocation. Many of these processes are currently scripted in current models and not easily adapted to changes in warfighting conditions.

Degree of Maturity: The technique itself is mature, although some fundamental research is necessary to determine alternative implementation schemes and the kinds of decisions it is most appropriate to solve.

Potential Air Force Application Area(s)/Benefit to the Air Force: Useful for Air Force resource allocation and force mix problems. We have used it to determine which aircraft perform which missions for each flight in a campaign. Genetic algorithms can also be used to solve any variety of complicated, nonlinear, optimization problems by using the computation horsepower with little intrusion into the simulation.

Major Players/Leaders Doing Research in this Technology Area: Research in nonmilitary areas has been extensively performed at various universities.

Gary Liberson
Rand Corp
Phone: (310) 393-0411 x-6807
E-mail: Gary_Liberson@rand.org

Bruce Dyke
McDonnell Douglas
Phone: (314) 232-3657

Enabling Technology #107: Human Representation Models for Semi-Automated Forces

Brief Description of the Technology Area: Computer simulation of wartime activities is a promising approach to planning and rehearsing conflicts. Current mission- and campaign- level models do not account for human performance degradation due to factors such as fatigue, stress, workload, environmental conditions, command and control breakdowns, chemical radiation effects, injuries, lack of training/experience, etc. The models' computer representation of intelligent entities often functions in a binary mode, i.e., they either complete the operational mission or fail to execute the mission. As gray areas of degraded performance and enhanced performance are not represented, these models produce results of lesser fidelity. Commanders can be given a false impression that individual combatants and forces can perform for sustained periods without performance degradation or mission impact. For AF combat models to be more predictive of battle outcomes at both mission and campaign levels, they must be able to account for powerful effects of momentary and long-term changes in individual and teamed performance.

Degree of Maturity: Investigations of human performance degradation under a variety of dynamic stress effects were conducted. A model to predict effects of fatigue/circadian disruption on human performance was developed. A model of the AWACS Weapons Director actions in response to ground and airborne threats was successfully implemented. The refinement of a fatigue model and a survey of compatible, mission-level models are underway.

Potential Air Force Application Area(s)/Benefit to the Air Force: Quantification and model representation of the dynamic effects of human performance degradation will permit more realistic risk assessment, particularly in network simulations. These efforts will significantly improve accuracy of existing and future AF models and simulations by addressing a component that is currently neglected, i.e., realistic, human-like performance of semi-automated forces. Enhanced model predictions will benefit development of command and control strategies, and overall planning, execution, and risk assessment for complex mission engagements.

Major Players/Leaders Doing Research in this Technology Area: Neal Takamoto, Systems Analyst, Systems Research Laboratories (SRL), Inc., is principle architect of the human fatigue model and technically responsible for the current demonstration version. Terry Benline, Technical Program Manager, SRL, is responsible for overall program planning related to human representation in models and simulations.

Comment: The DoD Modeling & Simulation Master Plan calls for development of authoritative representations of typical behaviors of individual combatants and crews/teams engaged in both hostilities and operations other than war. Integrating human behavioral representation into combat models will significantly enhance the sensitivity and operational realism of these higher order models.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Terry A. Benline, Systems Research Laboratories
P.O. Box 35482, Brooks AFB TX 78235 E-mail: tbenline@alcft.brooks.af.mil

Enabling Technology #108: Vestibular System Modeling

Brief Description of the Technology Area: An artificial neural network (ANN), hybrid software model of vestibular function is being investigated to improve assessment of the vestibular system. Recent advances in ANNs have provided new modeling techniques to narrow the gap between the model and real physiology systems. ANNs will be incorporated for enhancing the vestibular-ocular reflex (VOR) neuronal pathway model. The purpose is to enable a clinician/scientist to match VOR signal abnormalities to physiological changes without the need for prior "examples."

Degree of Maturity: The technology is immature. This area requires additional research to develop a working model/test; and areas of modeling and simulation that could benefit from assessing the vestibular function component of operator performance need to be identified. Lack of a usable test for vestibular function has precluded the evaluation of this important part of the human-machine loop.

Potential Air Force Application Area(s)/Benefit to the Air Force: The vestibular system induces a reflexive eye movement which helps a moving observer focus on a target. This is critical in dealing with the multisensory environment of flight. A good model of the vestibular system can be used to determine the operational significant levels of vestibular function or dysfunction and to locate the cause of vestibular dysfunction all without prior knowledge on similar cases. This will be of use to the military for selection, classification, and retention of pilots. Full evaluation of the vestibular system could also be important for evaluation of situational awareness and in possible future simulators that could include feedback loops to evaluate operator vestibular function. Many pharmacologic agents, some commonly prescribed chemotherapeutic and antibiotic drugs, have minor to very serious affects on the vestibular system. A vestibular system assessment could be a valuable adjunct to performance evaluation research on drugs that could be administered to aircrews. This could include psychoactive drugs like sleep-inducing agents for long-duration missions, or agents that produce more alertness in tired crewmembers.

Major Players/Leaders Doing Research in this Technology Area:

Lt Col Allen, Air Force Research
(formerly Armstrong Laboratory) Aerospace Medicine Directorate, AL/AOC
Brooks AFB TX 78235-5000
Phone: DSN 240-2177,

Elaine Mendoza, President and CEO
Conceptual MindWorks, Inc. (CMI)
4318 Woodcock Drive, Suite 210
San Antonio, TX 78228-1316
Phone: 210-737-0777
E-mail: emendoza@mail.teamcmi.com

Jun Zhou, Ph.D., Senior Research Engineer
jun@mail.teamcmi.com

Enabling Technology #109: Expert System Application to Computational Fluid Dynamics (CFD) Simulation Process

Brief Description of the Technology Area: Application of an expert system based either on forward chaining rules or procedural reasoning methods is key to the usability and proliferation of fluid dynamic simulation and modeling tools. This will be accomplished through on-line guidance and seamless interface of the multiple technologies associated with the CFD process, from geometry definition, grid generation, flow solver selection and execution to physical simulation and solution analysis, to name but a few. The objective of the work is to create an intelligent software environment that will assist CFD users of all ability levels in setting up and running CFD codes. The goal of the system is to facilitate the CFD design and analysis cycle by minimizing risk associated with improper input parameters, assisting in early detection of errors, reducing need for labor-intensive checks during execution, and improving user training.

Degree of Maturity: Expert system technology is already being applied as a decision aiding tool. The CFD process is also already being used on a developmental and separate module basis. The technology maturity required is the interface and knowledge base development required to infuse these two technologies. The CFD process is still in a growth and development stage in both algorithm and turbulence model development. Other growth areas involve the hardware and processing methodology used from PC to supercomputer and vector to massive parallel architectures. Mature Air Force application should begin by FY98-99.

Potential Air Force Application Area(s)/Benefit to the Air Force: Insertion of this technology would provide great benefits to the Air Force in virtually every application area. It will significantly reduce the time it takes to define a CFD problem set through physical simulation and analysis that in turn will increase use of CFD in design and analysis of flight vehicles. By interfacing the tools and aiding the user in correct applications, the proliferation and technical application will increase outside the laboratory environment, improving a wide variety of decision making activities.

Major Players/Leaders Doing Research in this Technology Area:

Dr Ashok K. Singhal
CFD Research Corp.
3325 Triana Blvd
Huntsville AL 35805
Phone: (205) 536-6576

Dr Laura C. Rodman
Nielsen Engineering & Research Inc
526 Clyde Ave
Mountainview CA 94043
Phone: (415) 968-9457 ext 233

Dr Leonard P. Wesley
Intellex
366 Masthead Ln
Foster City CA 94494
Phone: (415) 572-1646

Name, Address, Phone Number, and E-mail of Person Providing this Input:

Gregory O. Stecklein
Air Force Research Laboratory (formerly Wright Laboratory) - WL/FIMC
Bldg 450, 2645 Fifth St, Suite 7
Wright-Patterson AFB OH 45433-7913
Phone: (513) 255-3761
E-mail: teck@fim.wpafb.af.mil

Enabling Technology #110: Simulation of Lubricated Contacts and Dynamics of Rolling Element Bearings

Brief Description of the Technology Area: Numerical simulations of the lubricated contacts, both dry as well as lubricated with a fluid, have been going on for some time. Simulations of highly stressed lubricated contacts (elastohydrodynamic lubrication) are carried out using modified Navier-Stokes equations coupled with elasticity and energy equations. Models for simulations of stresses in multilayered rubbing solids are also being developed. Simulation of the dynamics of rolling element bearings is playing a major role in design and diagnostics of these bearings.

Degree of Maturity: The simulation techniques for modeling the EHL contact are mature. Models for three-dimensional streamlines and partially lubricated contacts are being developed. Models for calculating the stresses in coated solids are not mature yet, but are being worked on.

Potential Air Force Application Area(s)/ Benefit to the Air Force: This M&S technology has direct application to the basic and applied research being conducted/funded by the Air Force. Modeling of the lubricated contact provides guidance in research and development of lubricants for gas turbine engines and for space. Modeling of stress in the coated solids helps understand and optimize the multilayered coating systems of solid lubricants and wear-resistant materials. Simulation of bearing dynamics provides a tool to test the bearing/lubricant system without expensive engine testing.

Major Players/Leaders Doing Research in this Technology Area: The Society of Tribologists and Lubrication Engineers and American Society of Mechanical Engineers and many universities, private enterprises, and the Air Force Research Laboratory (formerly Wright Laboratory (POCs: Shashi Sharma, WL/MLBT; Nelson Forster, WL/POSL) are involved in this M&S Technology.

Name, Address, Phone Number, and E-mail:

Shashi K. Sharma
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/MLBT
Bldg 654, 2941 P St, Suite 1
Wright-Patterson AFB OH 45433-7750
Phone: (513) 255-9029
E-mail: sharmask@ml.wpafb.af.mil

Enabling Technology #111: Epitaxial Growth Modeling

Brief Description of the Technology Area: The purpose of the work is to use modeling and simulation to understand and control the epitaxial growth of semiconductor, thin-film materials. Although several modeling techniques are used, the most advanced and novel of these is the Monte Carlo model of epitaxial film growth. This is an established technique for simulating the process of epitaxial growth of semiconductor, single-crystal, thin films. We are applying this technique to new material systems of interest to the Air Force. Note that modeling and simulation is not the emphasis of this work but is used as a tool to analyze the physics of thin-film growth. Since established modeling techniques are used in this research, it is anticipated that this work will be of only marginal interest to the M&S community.

Degree of Maturity: The research in this area is continuous and ongoing. Results will be transitioned to semiconductor, thin-film growers both within the Air Force and in academia and industry (upon clearance) as they become available.

Potential Air Force Application Area(s)/ Benefit to the Air Force: Air Force application areas are primarily the use of simulation results to obtain improved thin-films for electronic and optical applications.

Major Players/Leaders Doing Research in this Technology Area:

Dr Dmitri Vvedensky
Dept of Physics, The Blackett Laboratory
Imperial College
London SW& 2BZ
United Kingdom

Comments: The work in this area both here and elsewhere is materials research driven. Significant advances in the understanding of thin-film growth of single-crystal materials have been obtained, resulting in the realization of novel, thin-film materials.

Name, Address, Phone Number, and E-mail:

Dr Donald L. Dorsey
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/MLPO
Bldg 651, 3005 P St, Suite 6
Wright-Patterson AFB OH 45433-7707
Phone: (513) 255-4474 ext 3236
E-mail: dorseydl@ml.wpafb.af.mil

Enabling Technology #112: Atomic-Level Modeling and Simulation of Materials

Brief Description of the Technology Area: Reliable atomic-level modeling and simulation of materials involve large-scale, first-principle calculations and atomistic simulations. These simulations are carried out using extensively the fast-developing, scaleable High Performance Computing (HPC) capabilities. Therefore, algorithms and methods are being developed to take the best advantage of such DoD HPC platforms, including n-scaling (n number of particles) for molecular dynamics atomistic simulations, Density Functional Theory methods scaling as N (N number of basis functions), and better scaling with N for Hartree-Fock, first-principle calculations. Large-scale, atomic-level modeling and simulation impacts material technology development and processing and benefits the community at large.

Degree of Maturity: This technology area has already been successfully applied to Air Force programs. However, there is still more research to be done, especially in method and code developments for parallel HPC machines.

Potential Air Force Application Area(s)/ Benefit to the Air Force: New materials and processes by computational design using atomic-level modeling and simulations will reduce elaborate experimentation and allow for the development of a more efficient design methodology. Indeed, the importance of computer development of new materials and processes with an atomic to structural level of understanding has been recently recognized for the future design of novel materials for AF applications (cf. New World Vistas Report, December 1995).

Major Players/Leaders Doing Research in this Technology Area:

Dr William A. Goddard
Caltech, 139-74
Pasadena CA 91125
Phone: (818) 395-2731
Email: debi@wag.caltech.edu

Name, Address, Phone Number, and E-mail of Person Providing this Input:

Dr Ruth Pachter
Materials Directorate, Air Force Research Laboratory
(formerly Wright Laboratory) - WL/MLPJ
3005 P St., Suite 1
Wright-Patterson AFB OH 45433-7702
Phone: (513) 255-6671 x-3158
E-mail: pachterr@ml.wpafb.af.mil

Enabling Technology #113: Quantum Mechanical Calculations and Molecular Dynamics Simulations for Obtaining Nonstructural Material Properties

Brief Description of the Technology Area: Thermodynamic properties of small molecules are being calculated using *ab initio* quantum techniques. Results of these calculations on halon replacements are being used to obtain kinetic rate equations for the many reactions that result when these materials are used to extinguish a flame. The complete set of rate equations makes possible modeling of the detailed behavior of a suppressant in a specified type of flame, including byproducts of its use. Ultimately, it will be possible to predict flame speed if the flame continues to burn, or extinguishment time if it is put out. This is presently in the realm of science, though it is expected to rapidly move into the engineering and then the design and manufacturing arena.

Degree of Maturity: Computational techniques for the quantum mechanical calculations, calculation of rate equations, and dynamical modeling of simple flames and flame extinguishment are mature. Computational resources to permit real-time modeling of flames and flame extinguishment of realistic size and complexity are close to being available. Within five years one would expect to see routine use of this technology in modeling the effect of extinguishment agents in a variety of flame conditions.

Potential Air Force Application Area(s)/ Benefit to the Air Force: The search for a drop-in replacement for Halon 1301 has been very costly, and replacements are less efficient on a weight or volume basis than the material being replaced. Future advances in both the agents and in the way agents are deployed in Air Force systems will benefit greatly by computer modeling. Benefits will be a consequence of shorter time for screening, making possible rapid screening of large numbers of species, along with a more complete description of byproducts that will facilitate toxicological studies. There will also be savings from not having to guard against toxic emissions from testing and not having to dispose of waste products.

Major Players / Leaders Doing Research in this Technology Area: Computational modeling of flame behavior is being pursued by the SUBSTHAL group in Europe (Dr Francois Baronnet, University of Nancy, France) and by the group in the Air Force Research Laboratory (formerly Wright Laboratory) - WL/MLBT and its collaborators (H. Paige). Other groups are involved in various aspects of testing or development of alternative materials, but no other groups are dedicated to computer modeling of halon alternatives.

Comments: In every area of scientific research, laboratory experiments are being replaced by computer simulations. Escalation of cost of materials, cost of waste disposal and, perhaps most importantly, cost of errors resulting from inadequate knowledge of materials and systems, will hasten the movement towards computer modeling and simulation.

Name, Address, Phone Number, and E-mail:

Harvey L. Paige, Air Force Research Laboratory (formerly Wright Lab) - WL/MLBT
Bldg 654, 2941 P St., Suite 1, Wright-Patterson AFB OH 45433-7750
Phone: (513) 255-9038 E-mail: paigehl@ml.wpafb.af.mil

Enabling Technology #114: Modeling of Composite Bolted Joints

Brief Description of the Technology Area: This project's objective is to develop a 3-D method for predicting the state of stress and the strength of composite laminates containing complex geometries and material discontinuities that are commonly found in bolted joints, composite doublers, etc. The project is divided into four tasks:

1. Use Spline Variational Elastic Laminate Technology (SVELT) to obtain the 3-D stress state for a structural composite laminate. The analysis shall be extended to solve complex geometry and loadings. Additional refinements are required to predict and incorporate progressive damage in the application of SVELT to composite bolted joints.

2. Conduct a theoretical and experimental investigation of the failure mechanisms of composite bolted joints, ultimately leading to a failure criterion for damage initiation and eventual laminate fracture. The exploratory study will begin with simple laminates and loadings and progress to include: contact stresses, clamping, etc. The damage progression will be monitored and examined to identify the initiation of primary failure mechanisms.

3. Use the SVELT analysis in conjunction with micromechanics to develop models at the constituent level. Using this approach, the initiation of damage at the fiber-matrix level shall be predicted using michromechanical failure criterion.

4. Initiate a formal ***Alliance*** between Defense industry primes (Lockheed, McDonnell Douglas) and the Air Force Research Laboratory, formerly Wright Laboratory--WL/MLBM, to collectively develop and apply SVELT to composite structures. Additionally, a user friendly, computer interface for the SVELT computer code is being developed for industry use.

Independent polynomial spline approximation of displacement and interlaminar tractions is utilized for stress analysis in laminates with an elastic inclusion. Spline approximation offers continuity of displacement, strain and stress fields within homogenous domains, and eliminates the inter element compatibility problems leading to unsatisfactory finite element results in the presence of field singularities. The polynomial spline approximation, ideally suited for problems concerned with singular solution behavior, has been applied successfully to three-dimensional, stress analysis in practical composites containing tens of plies. This accurate and detailed solution combined with a 3D failure criterion will provide engineers with a modeling/simulation tool to develop an optimized design for composite bolted joint structures.

Degree of Maturity:

1. Beta version of SVELT software for bolted joints will be provided to ***Alliance*** in July 1996. Updated version will be delivered in 1999.

2. The spline variation methodology is a generalized analysis technique but needs to be expanded for modeling arbitrary geometry. This is a long-term, over 10 years, effort.

Potential Air Force Application Area(s)/ Benefit to the Air Force: Program was in response to F-22 request. Currently, Boeing Defense & Space, McDonnell Douglas, Lockheed-Martin, Northrop-Grumman, Pratt & Whitney, Bell Helicopter, and Sikorsky participate in an Alliance and will use the software to analyze DoD composite structures with a focus on joint testing allowables.

Major Players/Leaders Doing Research in this Technology Area:

F.K. Chang, Stanford University
J. Eisenmann, Lockheed Martin
A. Sawicki and P. Grant, Boeing Helicopter
J. Hart Smith, McDonnell Douglas
F.L. Mathews, Centre for Composite Materials, ICST, UK
C. Poog, Institute for Aerospace Research, Canada
J. Baure, DASA, Germany

Comments: Spline variational theory offers many advantages over finite elements as previously stated. To date, it has demonstrated a 4X improvement in solution speed over 3D finite elements. Clearly, if successfully applied to composite joints, the next step is to establish an agreement with a software company for commercialization. SVELT may be the next generation FEM!

Name, Address, Phone Number, and E-mail:

Capt Jeffery R. Schaff
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/MLBM
Bldg 654, 2941 P St, Suite 1
Wright-Patterson AFB OH 45433-7750
Phone: (513) 255-3580

Enabling Technology #115: Modeling, Simulation, and Analysis (MS&A) Support to Aerospace Research and Acquisition

Brief Description of the Technology Area: MS&A has been recognized as a "critical process" at ASC. ASC leadership intends that MS&A be pulled together into a "focus area," which is a federation within which assets of the Air Force Research Laboratory (AFRL) and the Systems Acquisition Mission Unit (SAMU) (and perhaps nonASC organizations located at Wright-Patterson AFB, such as AFRL, AFIT, and NAIC) can join together to work any given problem. The sum of the capability within ASC is unequaled, and the potential synergy of such a federation unbounded. The physical lash-up of ASC facilities and capabilities will form a distributed, collaborative MS&A federation; distributed means that the facilities remain in their current locations, and collaborative means that high-speed computer networking permits the facilities to operate as if they were physically adjacent. This will permit us to accommodate any combination of constructive, virtual, and live simulations, from engineering to campaign levels. An important piece of this federation is a presentation theater in which the highest level decision makers can be immersed into a virtual simulation space to better understand ASC systems' potential. This piece, currently referred to as the Simulation and Analysis Facility, or SIMAF, is planned to begin construction in FY98.

Degree of Maturity: This technology has been demonstrated and applied for primarily ground vehicles and slow-flying aircraft. Network latency problems may still be an issue for quick-flying aircraft, which change their state drastically and frequently. The latency issue should be solved over the next two years.

Potential Air Force Application Area(s)/ Benefit to the Air Force: This federation of capabilities at ASC will pay huge dividends in several ways: exploring implications of technologies; providing capability to perform virtual prototyping, virtual manufacturing, and virtual testing of aerospace systems in acquisition; and providing the capability to "showcase" our systems.

Major Players/Leaders Doing Research in this Technology Area: Many people are working in this area, particularly the US Army, academia, and study houses. This area is at the top of the list of areas of interest to the Defense Modeling and Simulation Organization (DMSO), USAF/XOM, and others.

Comments: This capability is crucial to ASC's participation in the Joint Synthetic Battlespace, and perhaps to ASC's future role in aerospace acquisition. It is advocated by LGen Scofield, LGen Muellner, MGen Paul, MGen (Sel) Case, and BGen Bongiovi.

Name, Address, Phone Number, and E-mail:

Steve Wourms, ASC/XRA,
Bldg 11A, 1970 3rd St, Suite 2
Wright-Patterson AFB OH 45433-7209
Phone: DSN 785-5880 FAX: DSN 786-7603 E-Mail: wourmssj@xr.wpafb.af.mil

Enabling Technology #116: Virtual Manufacturing

Brief Description of the Technology Area: Virtual Manufacturing (VM) is the integrated use of design and production models and simulations to support accurate cost, schedule, and risk analysis. VM is distinguished from conventional modeling and simulation approaches by its focus on use of integrated models, simulations, and production analysis tools to gain an accurate systems engineering perspective of effects resulting from product and process decisions. Both AF and commercial industry requirements of affordability, producibility, and responsiveness drive the need for VM. The Air Force is particularly interested in reducing the manufacturing risk associated with transition from design into production. VM responds to these requirements by providing the user a set of integrated capabilities to visualize, validate, and optimize new production processes and paradigms with confidence, using analytical manufacturing simulation and production analysis tools. The ability to provide reliable estimates and feedback of manufacturing effects during Integrated Product/Process Development (IP/PD) is enhanced using VM capabilities which include process visualization, dynamic process planning, scheduling and resources allocation, tooling design/verification, process variability reduction, production flow analysis, bottleneck identification, and facilities planning.

Degree of Maturity: There is a near-term and long-term vision for VM. In the near term, VM stresses tool integration and is driven by the need to capitalize on existing industry investments in modeling and simulation and thereby provide an evolutionary path to full VM capability which exploits rapidly emerging computing, information, and networking technologies. The Air Force Manufacturing Technology Directorate and the Joint Strike Fighter Program Office (MT/JSF) are cosponsoring the Simulation Assessment Validation Environments program to help realize the near-term vision of VM. Through SAVE (see Comments), the near-term VM vision is currently in the initial stages of application in several AF weapon systems programs, most notably the F-22 and the JSF. By the end of the SAVE program in late 1999, an integrated manufacturing M&S environment will have been demonstrated and transitioned into the F-22 and JSF programs. The longer term focus of VM stresses development of tools and methods for efficiently capturing, integrating, and representing pertinent product/process data in the computer and presenting this data meaningfully to the user. This long-term VM vision is realizable in the next 10-15 years, however, more research is needed to fully realize this vision. Future critical research areas include product data modeling and representation, neutral data exchange between M&S tools and between IPT members, and security in a DIS environment.

Potential Air Force Application Area(s)/ Benefit to the Air Force: Insertion of VM technologies will result in more robust, affordable weapon systems across all sectors of defense manufacturing. A critical obstacle for the Air Force involves sidestepping the economy of scale paradigm to one centered on economies of scope, i.e., achieving the ability to economically produce multiple products in small volumes within a single enterprise. VM will ultimately provide the capability to make sound product mix and product flow decisions that are difficult to make today. A key driver to affordable weapon systems is the need to validate producibility up front in design. Analysis capabilities of tooling and the manufacturing environment as a whole, prior to commitment of costly physical production resources, is essential. Finally, VM will be

one of the techniques that enable multidisciplinary teams to work together. It can provide a common "language" for communicating manufacturing concerns and bringing the manufacturing engineer on an equal par with the designer.

Major Players/Leaders Doing Research in this Technology Area:

James W. Poindexter, Air Force Research Lab
(formerly Wright Lab) - WL/MTIM
2977 P St, Suite 6
Wright-Patterson AFB OH 45433-7739
Phone: (513) 255-8589
E-mail: poindejw@ml.wpafb.af.mil

Michael F. Hitchcock, Air Force Research Lab
(formerly Wright Lab) - WL/MTIM
2977 P St, Suite 6
Wright-Patterson AFB OH 45433-7739
Phone: (513) 255-7371
E-mail: hitchcmf@ml.wpafb.af.mil

Ram Sriram
Lockheed Martin Missiles and Space
O/96-20, Bldg. 254F, 3251 Hanover Street
Palo Alto CA 94304
Phone: (415) 354-5203
Sriram_ram@mm.rdd.lmsc.lockheed.com

Rendell R. Hughes
Lockheed Martin Aeronautical Systems
86 Cobb Drive
Marietta, GA 30063-0685
Phone: (770) 494-9441
E-mail: rhughes@netserve.lasc.lockheed.com

Edward Lin
Institute for Systems Research
Room 0111, ERB (093)
College Park MD 20742
Phone: (301) 405-6571

Comments: The Air Force Manufacturing Technology Directorate, MT, has been working to define the scope, benefits, technology voids, and opportunities related to VM. MT has conducted two primary workshops to address VM from the perspective of user needs/opportunities and technology feasibility. Technical reports from both workshops are available to download from http://www.isr.umd.edu/Labs/CIM/virtual.html or can be mailed by request to: Ms Lolita Mitchell; Technology Transfer Center; Air Force Research Lab, formerly WL/MTX; 2977 P Street, Suite 6; Wright Patterson AFB OH 45433-7739

In the VM near term, the MT/JSF Simulation Assessment Validation Environment (SAVE) program is currently demonstrating, validating, and implementing an open architecture environment to integrate modeling and simulation tools and methods used to assess effects on manufacturing of product/process decisions. The initial phase of the program establishes a core tool suite integrated via the Defense Advanced Research Projects Agency (DARPA)-developed Rapid Prototyping of Application Specific Signal Processors (RASSP) architecture. The core tool suite incorporates commercial off-the-shelf tools such as CATIA for design; Deneb's IGRIP, ERGO, and Quest for assembly and factory simulations; Cognition's Cost Advantage for cost modeling; Pritsker's Factor/AIM for scheduling and work flow simulations; and SAIC's Assure for risk analysis. Through the 5-year span of the effort, both level of tool-to-tool communication and number of tool types will be expanded. Benefits will be validated through a series of

demonstrations. The first of these demos will illustrate integrated modeling and simulation tools applied to initial design/manufacturing to optimize factory operations and product cost using an F-16 horizontal stabilizer box modification/upgrade.

The SAVE program leverages several related programs to allow integration of many different modeling and simulation tools. Efforts under the DARPA-funded RASSP Program, coupled with complementing activities through DARPA-funded programs, such as Simulation Based Design (SBD) Agile Infrastructure for Manufacturing Systems (AIMS), and National Industrial Information Infrastructure Protocol (NIIIP) programs, all contribute in allowing integration and communication of tools into an overall framework. Under the current SAVE effort, benefits to be measured include: Design-to-Cost Data Accuracy; Lead-Time Reduction; design change reduction; scrap, rework, and repair reduction; increased process capability; increased inventory turns; and, reduction of fabrication and assembly inspection. As a result of the SAVE Program's enhanced virtual design and manufacturing environment and tools, the program's benefits forecast a potential savings of 1½% to the F-22 current air vehicle average unit cost, or approximately $716K/aircraft. For a new acquisition system like JSF, the potential benefits are projected to be 2% - 3% of the total Life Cycle Cost. Additionally, through the SAVE program, MT is actively engaged with Sim TECH, the simulation software vendors' association, to promote and endorse the simulation environment being developed under the SAVE program to their user community.

Copies of SAVE briefings, as well as the SAVE Concept of Operations, Architecture Specification, I/O Specification, and Demonstration Description documents are available by request from:

James W. Poindexter
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/MTIM
2977 P St, Suite 6
Wright-Patterson AFB OH 45433-7739
Phone: (513) 255-8589
E-mail: poindejw@ml.wpafb.af.mil

or through the JSF ftp server at www.jast4.jast.mil. For JSF ftp server access, call Mr Bob Heyer at (703) 602-7390 ext 6689. Additional related WWW sites:

SAVE:	http://www.jast.mil
	http://skipper2.mar.external.lmco.com:80/jast/
CAME:	http://elib.cme.nist.gov/msid
University of Maryland VM site:	http://www.isr.umd.edu/Labs/CIM/virtual.html
Simulation-Based Design site:	http://sbdhost.parl.com/

Name, Address, Phone Number, and E-mail:

James W. Poindexter, Same as above

Enabling Technology #117: Nonlinear Indicial Response Modeling

Brief Description of the Technology Area: Nonlinear Indicial Response Modeling is a mathematical method for predicting any type of nonlinear physical process, such as nonlinear aerodynamics. It uses Nonlinear Indicial Theory, an extension of Linear Indicial Theory, which takes history effects into account and is exact in the mathematical limit sense. "Indicial Responses," which are responses showing differences between a motion with a step-and-hold and the same motion with a hold only, must be determined for the quantity to be predicted. These responses are incorporated within a superposition integral to yield the prediction. This integration must not cross "critical states" where differentiability is lost, therefore, these critical states must be located and properly accounted for. This nonlinear modeling has advantages over neural networks due to its physical basis, and Computational Fluid Dynamics due to its ability to provide extremely rapid, real-time predictions. Nonlinear Indicial Theory was developed several years ago with extensions of the basic theory being developed more recently, but this is the first known use of the theory to make aerodynamic predictions for dynamic maneuvers. This modeling work can be classified as engineering development. Due to its general nature, it does have potential application in a number of areas, including materials manufacturing.

Degree of Maturity: The feasibility of using Nonlinear Indicial Theory to make aerodynamic predictions for novel pitching maneuvers was demonstrated in a Phase I Small Business Innovation Research contract with Nielsen Engineering and Research, Inc. The work provided extremely accurate, extremely rapid, aerodynamic predictions and resulted in funding approved for a Phase II effort. The Phase II (two-year) effort will develop and deliver software to make aerodynamic predictions for arbitrary maneuvers.

Potential Air Force Application Area(s)/Benefits to the Air Force: The software package resulting from further development of the Indicial Prediction System would be an extremely valuable tool in several disciplines because of its general nature. Specific applications for aircraft designers include a fast, robust, flight simulation tool capable of modeling nonlinear and time-varying "plant" characteristics; and a multidisciplinary design optimization tool for the integration of nonlinear aerodynamics, structural dynamics, and control systems at early stages of design. Other potential applications include computational electromagnetics (e.g., design of optical switches), acoustic noise reduction (e.g., design of acoustic linears inside jet engines) and process control for material manufacturing.

Major Players/Leaders or Societies Doing Research in this Technology Area:

Dr Patrick H. Reisenthel
Chief Scientist
Nielsen Engineering and Research Inc.
526 Clyde Avenue
Mountain View CA 94043-2212
Phone: (415) 968-9457 Ext. 225
E-mail: phr@nearinc.com

Jerry E. Jenkins (and associates)
Air Force Research Laboratory
(formerly Wright Laboratory) – WL/FIGC
Bldg 146, 2210 Eighth Street, Suite 11
Wright-Patterson AFB OH 45433-7521
Phone: (513) 255-8485
E-mail: jerry@figc.flight.wpafb.af.mil

Vision of Your M&S Technology: This modeling would be used anytime it is necessary to accurately model nonlinear, unsteady, physical phenomenon. It is expected to find both governmental and private-sector applications.

Comments: This modeling work is documented in three references:

1. Reisenthel, Patrick H., (Dec 95). "Novel Application of Nonlinear Indicial Theory for Simulation and Design of Maneuvering Fighter Aircraft." Wright Laboratory TR-95-3094.

2. Reisenthel, Patrick H., (Jan 96). "Development of a Nonlinear Indicial Model For Maneuvering Fighter Aircraft," (AIAA Paper 96-0896). Presented at AIAA Aerospace Sciences Meeting, Reno, NV.

3. Reisenthel, Patrick H., (Jun 96). "Application of Nonlinear Indicial Modeling to the Prediction of a Dynamically Stalling Wing," (AIAA Paper 96-2493). Presented at AIAA Applied Aerodynamics Conference, New Orleans, LA.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Capt Deborah S. Grismer
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/FIGC
Bldg 146, 2210 Eighth Street, Suite 11
Wright-Patterson AFB OH 45433-7521
Phone: (513) 255-8494
E-mail: grismeds@b045mail.wpafb.af.mil

Enabling Technology #118: Flying Qualities of Manned Aircraft - Simulator Effectiveness and Required Techniques for Pilot-Induced Oscillation (PIO) Studies

Brief Description of the Technology Area: The current capability and techniques used in both ground-based and in-flight simulation studies for evaluation of PIO tendencies in manned aircraft are not reliable. An effort is underway to examine the degree of reliability of manned simulators or varying levels of sophistication relative to uncovering PIO tendencies. Based on these results, changes to simulation facility characteristics, aircraft model, flying task, and pilot motivational psychology will be evaluated to define the best combinations to use to discover PIO characteristics prior to flight test of the actual vehicle.

Degree of Maturity: This effort began in FY96 with a small-scale, in-house study of Air Force Research Laboratory (AFRL), formerly Wright Laboratory, simulation facilities. The research plan calls for an ambitious effort over the next five years with a very modest budget. This technology is planned to be incrementally available during the next five years with full availability in 2002.

Potential Air Force Application Area(s)/Benefit to the Air Force: This technology will benefit the Air Force immediately in future aircraft acquisitions or modifications by providing highly reliable techniques to use in manned simulation evaluations intended to show that a given design is PIO free. This benefit will be increasingly complete as the work progresses, and each additional improvement will reduce the risk of encountering unknown and potentially catastrophic PIO events in new or modified aircraft.

Major Players/Leaders or Societies Doing Research in this Technology Area: The international leader in this technology area is the Flight Control Division of AFRL (WL/FIG) which is sponsoring and directing several contracts with industry, performing in-house research in AFRL facilities, and providing technical support to the National Research Council's Committee on the Effects of Aircraft-Pilot Coupling on Flight Safety. Other major players include Boeing Aircraft Company, Douglas Aircraft Company, and Lockheed Aircraft Company.

Vision of Your M&S Technology: We expect the effectiveness of using ground-based and in-flight simulation for identifying PIO characteristics to get much more reliable in the future. This is due in part to our research on more effective evaluation approaches and techniques, and on the other research being conducted in virtual reality where the realism of the flight task can be greatly enhanced. This added realism will ultimately be very effective for PIO applications since one of the primary problems in uncovering PIO problems in the simulator has to do with getting the pilot to behave in a very excited fashion as a control threat increases. As the pilot task becomes more difficult, the pilot gain and frequency response characteristics change dramatically in flight such that PIO tendencies not present at lower gains are now excited. In the simulator where the threat is not real to the pilot, the pilot characteristics do not change enough to reliably provoke PIO tendencies. The desired effect of increased realism or increased flight task difficulty on uncovering PIO tendencies has been demonstrated in isolated cases, but not thoroughly defined in comprehensive scientific studies.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Wayne Thor
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/FIGC
Bldg 146, 2210 Eighth St., Suite 21
Wright-Patterson AFB OH 45433-7531
Phone: (513) 255-8497
E-mail: thorwa@wl.wpafb.af.mil

Enabling Technology #119: Real-Time Piloted Engineering Flight Simulation

Brief Description of the Technology Area: We use high fidelity models of aircraft and weapon systems implemented in piloted simulators to support the development and assessment of advanced flight vehicle and weapon system technology. Our models and simulations address the higher fidelity, real-time piloted simulation area. The significance to the M&S world is that we are able to very cost effectively assess advanced flight vehicle and weapon system technology in realistically simulated combat environments. The simulations can be classified as virtual simulations. The M&S work deals with technology development and assessment.

Degree of Maturity: The engineering simulation capabilities are mature and are being used for their intended purpose of integrating and assessing advanced flight vehicle technology.

Potential Air Force Application Area(s)/Benefit to the Air Force: It is of great benefit in that it provides a very cost effective and capable method of assessing advanced flight vehicle technology. These modeling and simulation tools can support flight vehicle and weapons system acquisition programs throughout their total life cycle. The Joint Strike Fighter (JSF) program is attempting to utilize a variety of modeling, simulation, and analysis tools throughout its development cycle. As an example, an effort is currently in process at the Air Force Research Laboratory to use networked, real-time, piloted simulation to investigate pilot vehicle interface and avionics issues for the JSF.

Major Players/Leaders or Societies Doing Research in this Technology Area: Some of the major players that have similar capabilities are airframe contractors such as Lockheed, McDonnell Douglas, Northrop Grumman, and Boeing. Also, the Navy at Patuxent River has a similar capability.

Vision of Your M&S Technology: The vision for the future is to have our locally networked, eight piloted flight stations networked to simulation and test facilities located around the U.S. and around the world. Improved network performance and protocols are required for the real-time, piloted, engineering-type simulators. We are involved in several efforts to improve networking capability. Also, there is a plan in development to collocate and integrate the ASC/XR Analysis function with the Air Force Research Laboratory (formerly Wright Laboratory) engineering simulation facilities in Building 145. This will provide an enhanced capability to incorporate fully integrated modeling, simulation, and analysis into the acquisition process.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Don R. Gum
Phone: (513) 255-4690
E-mail: gumdr@wl.wpafb.af.mil

Enabling Technology #120: Subsystems Integrated Design Assessment Technology/ Integrated Subsystems Interactions Tradeoff Evaluation (SIDAT/INSITE)

Brief Description of the Technology Area: SIDAT/INSITE is a concept for enabling aircraft engineering design assessment, beginning in the earliest possible stages of the design process when design flexibility is at its greatest. The capability offered by this technology will enable Air Force engineers to assemble and "flight test" a virtual aircraft in a computer simulation environment. SIDAT will provide a roadmap, along with baseline requirements and specifications, for implementing the SIDAT/INSITE capability. This program is exploring the use of exit energy (EXERGY)-based models for all air vehicle subsystems' functions. These models, when implemented within a virtual prototyping environment, will enable effective design trade studies across traditional technology boundaries during conceptual design or redesign of a weapon system.

Degree of Maturity: A demonstration of the SIDAT/INSITE capability of SIDAT/INSITE technology will be complete by 2002. This will be a capability demonstration only, and will require significant additional commercial development in order to make a complete virtual prototyping capability.

Potential Air Force Application Area(s)/Benefits to the Air Force: Early optimization of subsystems' component mixes and identification of developmental risks will provide a direct benefit to acquisition risk management and vehicle development cost. Optimized management of energy--through more effective utilization, transport, storage, disposition, and reuse--will permit future vehicles to be smaller and produce less waste energy, thereby enhancing LO. Once demonstrated, the envisioned capability can be extended to encompass the entire vehicle concept development.

Major Players/Leaders or Societies Doing Research in this Technology Area: Lockheed Martin Aerospace Company is the prime contractor on the SIDAT program. In addition, the following organizations have expressed interest in, and committed to, providing support to the SIDAT program: McDonnell Douglas, Boeing, Northrop, Sundstrand, the Air Force Research Laboratory (formerly WL/POPS), Texas Instruments, Allied Signal, Georgia Tech, and SAIC.

Vision of Your M&S Technology: As computer models for various subsystems components and technologies are expanded and refined, the need for assembling and testing physical breadboard subsystems will be reduced or eliminated entirely. Virtual vehicle prototyping, perhaps employing intelligent objects that precisely mimic actual mechanical components, has a potential to enhance productivity and manufacturing competitiveness of all U.S. industries. From concept to preproduction, future vehicle design, test, and evaluation will be carried out in a virtual world, utilizing computer simulation and assessment to ensure the best overall application and mix of technologies for achieving the desired platform capability.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Donald J. Reese, Jr. (513) 255-3021 reesedj@b045mail.flight.wpafb.af.mil

Enabling Technology #121: Computational Fluid Dynamics (CFD) and Combustion

Brief Description of the Technology Area: We develop, validate, and employ CFD codes that use a variety of features to solve real scientific and engineering problems. We are developing advanced direct numerical simulation methods for solution of time-dependent, Navier Stokes equations and advanced combustion chemistry models using hydrogen and various hydrocarbon fuels. New numerical methods and chemistry models are validated using fundamental fluid dynamics and combustion experiments. Developed codes are used to solve engineering problems to include simulation of advanced gas turbine engine combustors and of endothermic heat transfer and fuel system fouling due to extreme heat loading of advanced fuels and endothermic fuel systems.

Degree of Maturity: The technology can be used as it evolves to make basic scientific advances and development of fuel system and combustor design. It should be fully mature within seven years, hinging upon current rates in advancement in computer speed and memory.

Potential Air Force Application Area(s)/Benefits to the Air Force: As this technology matures, it will help develop the basic knowledge of the combustion process through modeling basic combustion phenomena. These basics can then be applied to enhance advanced gas turbine engine combustors. During development, this technology can be used as a design aid for advanced combustors. Once mature, this technology will be an accurate, cost-effective, environmentally friendly tool for design of advanced gas turbine engine combustors.

Major Players/Leaders or Societies Doing Research in this Technology Area:

Dr W. Melvyn Roquemore	Air Force Research Lab (WL/POSC)	DSN 785-6813
Dr R. Ni	Pratt and Whitney	(860) 565-1383
Dr A. Singhal	CFD Research Corporation	(202) 536-6576
Dr V. Katta	Innovative Scientific Solutions Inc.	(513) 255-8781
Dr R. Stubbs	NASA Lewis Research Center,	(216) 433-2452
Dr H. Mongia	General Electric Aircraft Engines	(513) 423-2552)
Dr M. Razdan	Allison	(317) 230-6404

Vision of Your M&S Technology: To simulate time-dependent, 3D, combustion-reacting, and two-phased flows in complex geometries. Currently, technology is at a state that 2D, time-dependent, combustion simulations using hydrogen and methane of simple geometries, is possible on desktop workstations. With advances in computer speed and memory, we expect to simulate the extremely complex environment in a gas turbine engine combustor using complex chemistry for fuels, such as JP-8 and advanced hydrocarbon fuels. This technology will also be used as a primary design tool in heat transfer to endothermic fuels, including fuel degradation and fuel system fouling effects due to fuel breakdown.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Dr W. Melvyn Roquemore, Air Force Research Lab--formerly WL/POSC; Bldg 490, 1790 Loop Road North; Wright-Patterson AFB OH 45433-7103 E-mail: melr@ward.appl.wpafb.af.mil

Enabling Technology #122: Rolling Bearing Dynamics Simulation

Brief Description of the Technology Area: Rolling bearing dynamics simulation has been under development for several years. The simulation is used for the design of bearings and for the determination of bearing failures. There are multiple factors that affect the dynamics of bearings. Geometry, materials, housing/shaft fits, operating temperature, operating speed, operating load, and lubricant performance are some of the variables that affect bearing dynamics. The simulation eliminates the long iterative process of bearing design by testing. The simulation process clearly benefits the bearing community.

Degree of Maturity: This technology has been applied to several Air Force programs and commercial applications as well. One simulation, ADORE (Advanced Dynamics of Rolling Elements), has been used to a great extent, but still needs further improvement. Enhancements to the thermal modeling capability are being addressed currently by an Air Force program.

Potential Air Force Application Area(s)/Benefit to the Air Force: Insertion of this technology will provide great benefits to the Air Force. It will significantly reduce the time required for bearing designs and analysis of failure modes.

Major Players/Leaders or Societies Doing Research in this Technology Area:

Dr Pradeep K. Gupta
PKG, Inc.
117 Southbury Rd
Clifton Park NY 12065-7714

Crawford Meeks
AVCON
5210 Lewis Rd
Agoura Hills CA 91301-2662

Vision of Your M&S Technology: Several reports have been published as well as a book by Pradeep K. Gupta entitled, "Advanced Dynamics of Rolling Elements." Published technical reports include: AFWAL-TR-81-4148; AFWAL-TR-86-2054; WRDC-TR-89-2059; WL-TR-91-2129; and WL-TR-95-2135.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Garry D. Givan
Air Force Research Laboratory
(formerly Wright Laboratory) - POSL
1790 Loop Rd N
Wright-Patterson AFB OH 45433-7103
Phone: (513) 255-1286
E-mail: givangad@wl.wpafb.af.mil

Enabling Technology #123: Conceptional Technology Integration

Brief Description of the Technology Area: Conceptual Technology Integration is the process by which diverse technologies are consolidated into notional aircraft concepts for "whole airplane" analysis. Through Conceptual Aircraft System Design and Analysis Toolkit, or CASDAT, we will provide the missing link between technologists' tools and simulator modelers by integrating various technology suites into a viable configuration to be analyzed. With the analysis tools included in CASDAT, we will be able to determine basic aerodynamic, stability and control, and mission improvements the technologies yield, saving valuable simulator time by eliminating unfavorable combinations. In addition, the geometry modeler will be compatible with higher level analysis codes and wind tunnel model generation programs as needed.

Degree of Maturity: A survey of industry methods has just been completed. The best codes offered to the Air Force will be consolidated into a Government-only code to protect industry proprietary rights. As we are taking advantage of the best of industry's codes, the major remaining hurdle is linking them together into a seamless, easy-to-use package. Discussions with DARPA suggest that they are working on an "executive" that could serve this function. If their system can be teamed with industry codes, we could be fully operational with the new system in three to five years.

Potential Air Force Application Area(s)/Benefits to the Air Force: Through creative combinations of dissimilar technologies, the possibility of a new "whole" that is greater than the sum of the parts is likely. For example, a creative method of weapons carriage may open valuable real estate for the new engine inlet system that results in a much smaller aircraft than either technology would yield alone.

Major Players/Leaders or Societies Doing Research in this Technology Area:

Dennis L. Carter, P.E.
Air Force Research Laboratory
(formerly Wright Lab) – WL/FIIB
2130 Eighth Street, Suite 1
Wright-Patterson AFB OH 45433-7543
Phone: DSN 785-4294
E-mail: carterdl@b045mail.wpafb.af.mil

Paul Gelhausen
NASA/Ames Research Center
Mail Stop 237-11
Moffett Field CA 94035
Phone: (415) 604-5701

Dr Dimitri Mavris
School of Aerospace Engineering
Georgia Institute of Technology
Atlanta GA 30333-0150
Phone: (404) 894-3343
dimitri.marvis@aerospace.gatech.edu

Linda K. Poole
Lockheed MartinTactical Aircraft Systems
Post Office Box 748
Mail Zone 2655
Fort Worth TX 76101
Phone: (817) 763-2096

Frank Neumann
Boeing Defense & Space Group
P. O. Box 3707, #MS 4C-70
Seattle WA 98124-2207
Phone: (206) 662-0083
neufdx00@ccmail.ca.boeing.com

James E. Cupstid
McDonnell Douglas Aerospace
Advanced Sys & Technology - Phantom Works
Mailcode 106 7126, P.O. Box 516
St Louis MO 63166-0516
Phone: (314) 232-4941
jcupstid@swsmtp01.mdc.com

Vision of Your M&S Technology: We anticipate a rapid prototyping methodology for generating new configurations for more detailed analysis and wind tunnel testing. In addition, with the downsizing of the Laboratory staff, much seasoned talent is leaving government service. CASDAT will simplify the design process so that the designer can spend his time studying the design instead of trying to figure out a legacy code that no one really understands any longer. By putting intelligent helps into the code, the designer will not have to memorize the Military Specifications. As stated above, we are taking advantage of the best that industry has to offer and bundling it together as needed. This plan was briefed to the Fixed-Wing Vehicle Integrated Product Team (IPT), created by Dr Dix, and received favorable response and support by the IPT members.

Comments: The Air Force Research Laboratory (formerly Wright Laboratory) is tasked to develop new technologies for the next generation of Air Force flight vehicles. To do this, we have dedicated specialists utilizing computer codes developed at considerable expense to analyze the individual disciplines. In addition, we have world-class flight simulation facilities that can determine the effectiveness of a new aircraft configuration in a "near real-world" environment. What is lacking is an efficient method of linking the technologists with the simulators. Through Conceptual Technology Integration, we are developing a methodology where the individual technologies can be quickly integrated into complete notional aircraft concepts to determine the most beneficial combination of technologies. The specialist codes are good for predicting the shock location on a wing, but are too detailed to conduct trades on the location of the wing on the aircraft in a timely manner. Integration codes have not received the favorable attention over the years that the specialist codes have. We are still using codes from the 70s and are best termed "User Hostile." CASDAT will replace the integrators on a par with the technologies.

Name, Address, Phone Number, and E-mail of Person Providing This Input:

Dennis L. Carter, P.E.,
Air Force Research Laboratory
(formerly Wright Laboratory) - WL/FIIB
Bldg 45, 2130 Eighth Street, Suite 1
Wright-Patterson AFB OH 45433-7543
Phone: DSN 785-4294
E-mail: carterdl@b045mail.wpafb.af.mil

Enabling Technology #124: Modeling of Visual Discrimination With and Without Impairments

Brief Description of Technology Area: A simulation of any type of visual impairment that might interest the Air Force. Permanent laser-induced retinal damage is important but only a tiny subset of this critical component of human performance. Other examples are laser-induced, flash blindness for minutes (e.g., this happened to a Southwest Airlines plane in Las Vegas--pilot got zapped by a casino show laser--the co-pilot had to take over); canopy glare caused by a laser which does not hurt the pilot's eyes but impairs his view; or loss in vision due to laser goggles, cloud scatter, and a variety of other causes to include pharmacologic-agent use to enhance performance or provide rest. The Air Force may also be interested in visual discrimination where no impairment exists, such as IFF (i.e., the shooting down of American helicopters by mistake in Iraq).

Degree of Maturity: Technology is immature, especially for modeling of impairments. Scientists have been modeling detection and discrimination for years, usually on very simple patterns. For complex patterns, there is still a long way to go.

Potential Air Force Application: Potential benefit should be enormous if accurate models can be developed. Lasers are light and cheap; a good weapon for poor countries; and their military threat is great. In addition to known use in aviator flashblindness, handheld lasers could be used to flashblind troops in urban warfare or terrorist situations. As noted above, they can cause permanent eye damage, serious flashblindness, and canopy glare. Furthermore, laser protective goggles can further impair vision, and the level of impairment can be modeled. Vision models that actually discriminate targets from complex background are minimally effective. Target discrimination will be a major factor in unmanned vehicles. Vision model-based, pattern recognition algorithms combined with other sensing modalities could be used in unmanned situations.

Major Players/Leaders Doing Research in this Technology Area: Lt Col McLin, Armstrong Laboratory (AL\OEO), Human Systems Center, Brooks AFB TX 78235, DSN 240-3625; Dr Harry Zwick, US Army Medical Research Detachment, Brooks AFB TX 78235, DSN 240-4620. Prof Wilson Geisler at the University of Texas at Austin has AFOSR grants to develop vision models. The OPR is AFOSR/NL, Bolling AFB DC, DSN 297-4278. Jan Walraven in Holland has worked on making signs and displays better for colorblind people--he is quite famous and some of his work would be applicable. Andrew Watson at NASA-Ames is another famous vision modeler.

Elaine Mendoza, President and CEO
Tom Arnow, Senior Research Engineer
Conceptual MindWorks, Inc. (CMI)
4318 Woodcock Drive, Suite 210
San Antonio TX 78228-1316
Phone: 210-737-0777
E-mail: mendoza@mail.teamcmi.com
tom@mail.teamcmi.com

Enabling Technology #125: Decision Logic Design

Brief Description of Technology Area: The subarea addressed here is that of matching the methods used to implement decision logic to the needs of users of the logic. Decision on logic design has to do with the development of logic for both computer simulations (simulating the behavior of humans in military scenarios) and for the logic that is embedded in automated components of fielded systems. This is a broad area threat that endeavors to exploit technology that already exists and adapt it to military simulation. While there is certainly a need to improve the state of the art for various specific decision logic methods and techniques, a problem that may be of greater significance is the difficulty practitioners have in choosing among the decision modeling methods that are currently available and implementing alternative approaches.

Degree of Maturity: A preliminary methodology exists to assist developers of decision logic in selecting the best available methods with respect to their intended use of the logic. While by no means mature, the preliminary methodology can be used immediately, and even the preliminary version should provide value added in the form of improved designs.

Potential Air Force Application Area(s)/Benefit to the Air Force: One of the reasons for the importance of simulated human decisions is the strong influence that human decisions play in determining the results of simulation models used to inform decision makers. Improvements to this logic that result in increased fidelity benefit Air Force decision makers by improving their ability to use simulation to support their own needs. Besides increased realism, improved logic for simulations can result in reduced M&S development risk, improved M&S responsiveness to quick response tasking, and a broadened range of M&S applicability.

Major Players/Leaders Doing Research in this Technology Area:

Dr Robert Kerchner	RAND	202-296-5000 x 5324	kerchner@rand.org
Mr James Heusmann	DMSO (SAIC)	703-824-3413	heusmann@msis.dmso.mil
Dr Stephen Downes-Martin		413-582-0183	70673.3172@compuserve.com

Comments: A RAND annotated briefing presenting a methodology for rationalizing the selection of decision logic should be available very shortly. It includes an assessment of our current inability to match decision logic techniques to the needs of target applications, and suggestions for additional research areas pertinent to the AF/XOM inquiry. Contact Robert Kerchner for a draft version of this briefing.

Enabling Technology #126: Human Performance Modeling

Brief Description of the Technology Area: The technology area is human performance modeling, particularly incorporating human performance limitations into computer-generated forces. Human performance modeling is important for computer-generated forces (simulated human beings) when factors like stress and workload play a critical role in determining combat effectiveness. Pilot workload is one such area, and the limited "processing ability" of humans involved in C2 functions provides a second important example. Currently, analytic models with simulated human participants do very little to capture human performance limitations. Improvements in this area would aid analysts by greatly improving the utility of simulation for studying systems where human performance limitations play a major role. In current contexts, capturing time-critical C2 situations, such as attacking "critical mobile targets" is an area where timelines are critical, so human performance capabilities may determine whether system concepts are workable. Note that the use of virtual participants in advanced distributed simulation (ADS) exercises, while vital, is insufficient--it is impractical to conduct enough such exercises to explore all system variations and CONOPS.

Degree of Maturity: I will address only the human performance area of workload modeling here. Promising prototype models that can be used in simulations to incorporate human workload limitations exist, but the degree of maturity is poor. The prototypes need to be validated, improved, and adapted to particular contexts. A proof-of-concept prototype I developed (originally for the Air Force Research Laboratory, formerly Armstrong Laboratory, in Mesa AZ) might be made usable in a simulation, for real applications. Additionally, it would be necessary to obtain calibrating data, perhaps from ADS experiments measuring the performance of virtual human participants.

Potential Air Force Application Area(s)/Benefit to the Air Force: One of the reasons for the importance of simulated human decisions is the strong influence that human decisions play in determining the results of simulation models used to inform decision makers. Improvements to this logic that result in increased fidelity benefit Air Force decision makers by improving their ability to use simulation to support their own needs. Again, improving the ability to represent workload limits in simulated humans is the improved usability of simulations for situations where workload is an important determiner of combat outcomes.

Major Players/Leaders Doing Research in this Technology Area:

Dr Robert Kerchner
RAND
Phone: (202) 296-5000 x 5324   E-mail: kerchner@rand.org

Dr Herbert H. Bell
Air Force Research Laboratory
Warfighter Training Research Division
6001 South Power Road, Bldg 561
Mesa AZ 85206-0904
Phone: (602) 988-6561; DSN 474-6561   E-mail: herbert.bell@williams.af.mil

Enabling Technology #127: Data Warehousing

Brief Description of the Technology Area: This idea is to create a more effective way to collect and provide M&S data by leveraging database and networking capabilities. Perhaps the most difficult and time-consuming aspect of M&S is the availability and accessibility of data. Data warehousing provides the technical means for simplifying these tasks. It also provides the motivation to resolve a variety of release authority and organizational impediments for data sharing.

Degree of Maturity: Data warehousing is a relatively new concept in data management. The technology is mature enough to begin Air Force use although some additional research should be done.

Potential Air Force Application Area(s)/Benefit to the Air Force: Data warehousing could vastly improve the timeliness and quality of Air Force M&S activities by providing ready sources of data.

Major Players/Leaders Doing Research in this Technology Area: Various in the community.

Contact:

Iris Kameny
Bart Bennett
RAND
Phone: (310) 393-0411
E-mail: Iris_Kameny@rand.org
Bart_Bennett@rand.org

Comments: Some DMSO projects are looking into data warehousing and other resolving M&S data needs.

Enabling Technology #128: High-Resolution, Microlaser-Based, Helmet-Mounted Display

Brief Description of the Technology Area: A microlaser-based, helmet-mounted display (HMD) configuration has been identified which promises a quantum leap in performance characteristics when compared to conventional cathode ray rube- and liquid crystal-based HMDs. Under development is an HMD monochrome system, modularized to readily upgrade to full color, which has 60 Hz, high definition television (HDTV) resolution of 1920 horizontal by 1080 active vertical pixels, and a brightness capability of 1,000 ftL. Because of innovative parallel scan technology being developed, this system is directly amenable to much higher full-color resolutions for future versions. This innovative parallel scan technology could ultimately lead to video formats greater than 10 million pixels/eye with very large color gamuts and brightness levels of 10,000 ftL.

Degree of Maturity: The microlaser-based HMD is in the final stages of a Phase II Small Business Innovative Research (SBIR) award. The construction of a monochrome, 60 Hz, HDTV resolution HMD with 50% see-through will be completed soon. Characterization and image quality evaluation of the display will follow to determine brightness, uniformity, resolution, contrast, distortion, flicker, and gray levels.

Potential Air Force Application Area(s)/Benefit to the Air Force. A bright, high-resolution, see-through, HMD in a lightweight, compact, cost-effective package would have potential Air Force benefit in several areas. The microlaser-based HMD could provide high quality imagery in flight simulators either as a supplement of other displays, or on a stand-alone basis, where all the imagery is displayed on the HMD. A bright, high-resolution, lightweight HMD could be used in tactical aircraft environments to display high off-boresight angle targeting information as well as high-resolution, Forward Looking InfraRed (FLIR), night-time imagery.

Major Players/Leaders Doing Research in this Technology Area:

Mr Phil Peppler
Air Force Research Laboratory
Warfighter Training Research Division

Name, Address, Phone Number, and E-mail:

Mr Phil Peppler
Air Force Research Laboratory
Warfighter Training Research Division
6001 South Power Road, Bldg 558
Mesa AZ 85206-0904
Phone: (602) 988-6561
E-mail: peppler@hrlban1.aircrew.asu.edu

Enabling Technology #129: Microlaser-Based Projection Display for Simulation

Brief Description of the Technology Area: Flight simulator visual displays still cannot provide real-world resolution, brightness, contrast, and detail. The Air Force Research Laboratory/Warfighter Training Research Division calculates that a projector capable of projecting 4000 x 4000 line imagery is required to give a pilot training air-to-air and air-to-ground missions the eye limiting resolution he requires in a visual display. Recent developments in microlaser technology now promise the means to construct a portable, efficient, and relatively low-cost laser projector display to meet this requirement. The microlasers combined with high-contrast parallel modulators under development can produce very high-resolution, high-contrast, 24-bit color imagery. As the microlasers develop and their power increases, so will the potential for very high brightness.

Degree of maturity: The microlaser-based projector for simulation is in Phase II of a Small Business Innovative Research (SBIR) award. This program is leveraging commercial microlaser projector development, but increasing the resolution levels not normally required for business applications. Resolutions are being developed for high-definition television (HDTV) and beyond. This program will demonstrate a 1,000 lumen, HDTV resolution (1920 x1080), full color, brassboard projector in early 1998. This is an intermediate step in technology toward a next-generation, full-color, 4000 x 4000 line, 2,500 lumen projector.

Potential Air Force Application Area(s)/Benefit to the Air Force: Flight simulators are a critical part of aircrew training systems, providing a cost-effective alternative to the expense of flying aircraft. However, the displays in these simulators have significant deficiencies in performance limiting their realism and effectiveness. Resolutions currently are limited to the equivalent of 20/80 visual acuity, far less than that needed for target identification in air-to-air and air-to-ground training missions. This technology shows great potential for raising the performance of projection displays and thereby providing the required realism.

Major Players/Leaders Doing Research in this Technology Area:

Mr Phil Peppler
Air Force Research Laboratory
Warfighter Training Research Division

Name, Address, Phone Number, and E-mail:

Mr Phil Peppler
Air Force Research Laboratory
Warfighter Training Research Division
6001 South Power Road, Bldg 558
Mesa AZ 85206-0904
Phone: (602) 988-6561
E-mail: peppler@hrlban1.aircrew.asu.edu

Enabling Technology #130: A True Three-Dimensional Monitor for Aerospace Applications

Brief Description of the Technology Area: A three-dimensional monitor is being developed for the direct display of three-, or higher, dimensional information. The device is constructed of a three-dimensional array of transparent volumetric pixels or voxels. When these elements are excited optically, through a fiber optic waveguide, they fluoresce. The sum of many fluorescing voxels thus composes a three-dimensional image that allows us to view a three-dimensional world.

Degree of Maturity: The three-dimensional monitor is nearing completion of a Phase II Small Business Innovative Research (SBIR) award. An 80 x 80 x 48 voxel prototype is being constructed to assist in integration of three-dimensional video. Video from an existing brief/debrief station is being reformatted for three dimensions. At completion of the SBIR phase II, a larger, higher voxel monitor is expected.

Potential Air Force Application Area(s)/Benefit to the Air Force. The ability to present a transparent, three-dimensional image would provide enhanced realism to many applications including medical imaging and military displays. Three-dimensional imaging would allow pilots to view aircraft, terrain, and associated threat zones, chaff, and surface-to-air (SAM) trajectories from a new and informative perspective. Situational awareness of a single pilot or a group of strategy planners would be significantly enhanced by the ability to display three-dimensional information in three-dimensions.

Major Players/Leaders Doing Research in this Technology Area:

Mr Phil Peppler
Air Force Research Laboratory
Warfighter Training Research Division

Name, Address, Phone Number, and E-mail:

Mr Phil Peppler
Air Force Research Laboratory
Warfighter Training Research Division
6001 South Power Road, Bldg 558
Mesa AZ 85206-0904
Phone: (602) 988-6561
E-mail: peppler@hrlban1.aircrew.asu.edu

Enabling Technology #131: PC-Based Image Generator for Flight Simulation

Brief Description of the Technology Area: A plan is being developed to use PC-based image generators developed for the game and entertainment industry, in a low-cost yet high-fidelity image generator for flight simulation. Requirements are to support 1024 x 1024 resolution, 60 Hz update rates, 24-bit color, anti-aliasing, and texturing. Considerations are also being made for advances in technology, support for an interoperable, joint training environment, and a programmable, video output interface. The approach will be to utilize commercial off-the-shelf (COTS) hardware and software and create image generator manager software to provide a flexible means of displaying the terrain database, manipulating environmental effects, managing networked entities within a heterogeneous training environment, and updating the ownship position.

Degree of Maturity: This project is in the planning and conception stage as a Phase I Small Business Innovative Research (SBIR) award. In January 97, candidate PC-based image generators will be demonstrated and an SBIR Phase II prototype development proposal will be submitted.

Potential Air Force Application Area(s)/Benefit to the Air Force: The historically high cost of computer image generators for rendering out-the-window imagery has been a barrier to wide deployment of flight simulators. However, commodity-priced PCs, which have increasingly powerful processors and high-speed busses, can be integrated with emerging low-cost, high-performance image generators to provide a low-cost, out-the-window, visual image that meets Air Force fidelity requirements.

Major Players/Leaders Doing Research in this Technology Area:

Mr Phil Peppler
Air Force Research Laboratory
Warfighter Training Research Division

Name, Address, Phone Number, and E-mail:

Mr Phil Peppler
Air Force Research Laboratory
Warfighter Training Research Division
6001 South Power Road, Bldg 558
Mesa AZ 85206-0904
Phone: (602) 988-6561
E-mail: peppler@hrlban1.aircrew.asu.edu